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The University of Michigan
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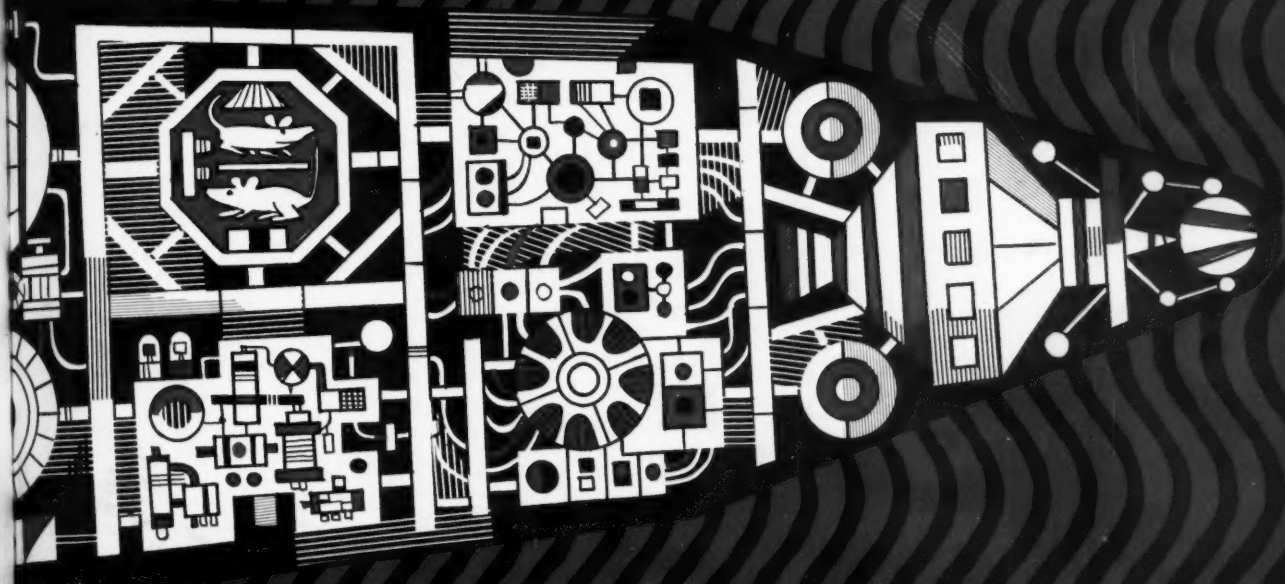
ELECTROMECHANICAL

components & systems | DESIGN

MARCH 1959



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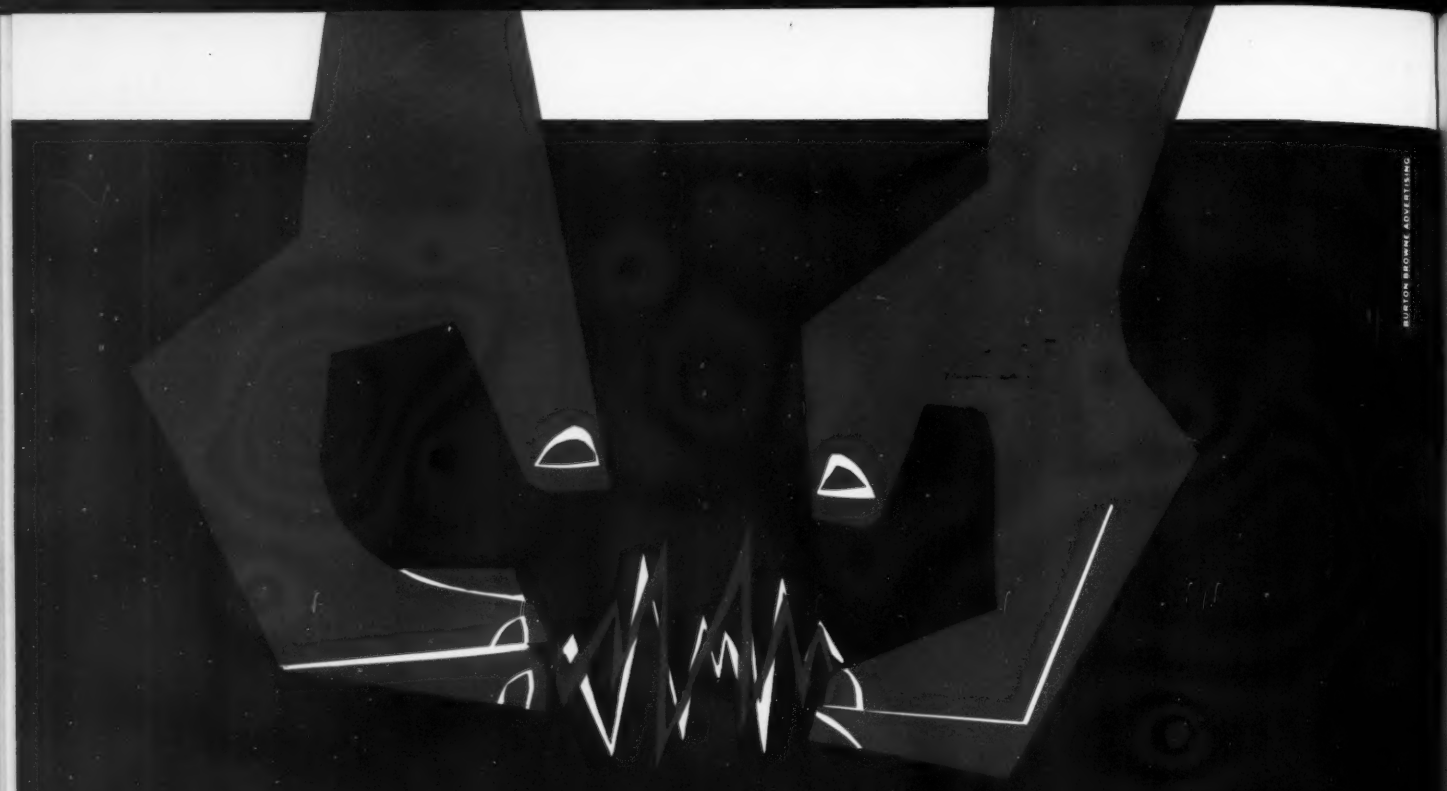
components design 4

ENVIRONMENTAL TESTING



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VOL. 3, NO. 3

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ELECTROMECHANICAL components & systems DESIGN

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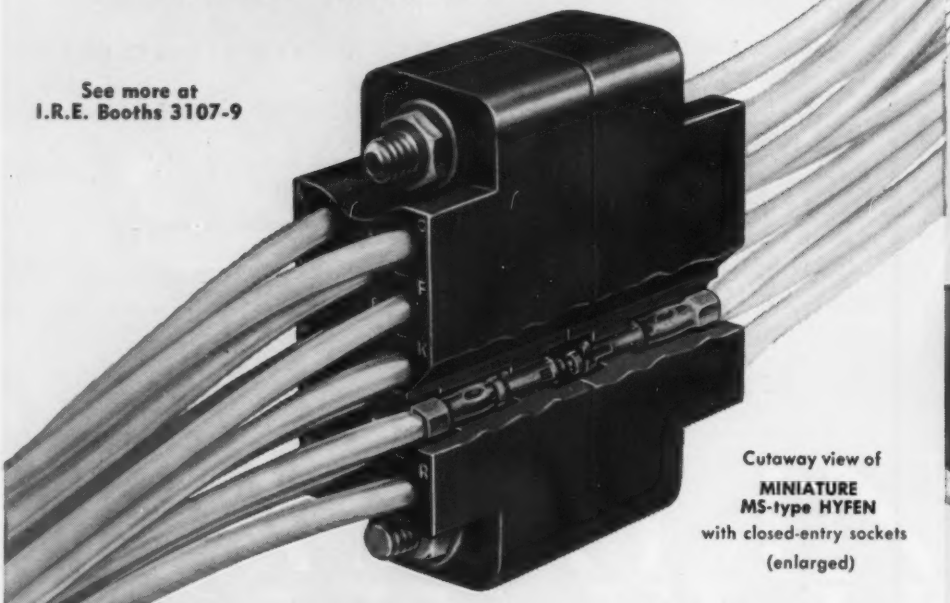
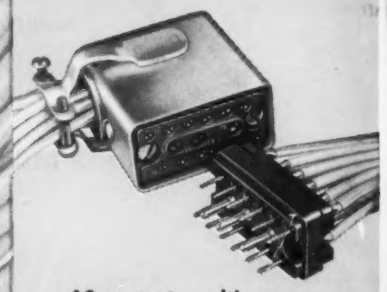
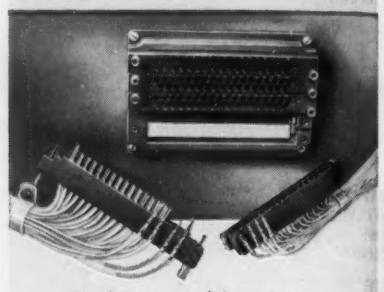


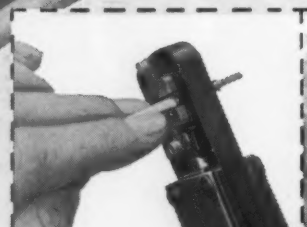
Cutaway view of
MINIATURE
MS-type HYFEN
with closed-entry sockets
(enlarged)



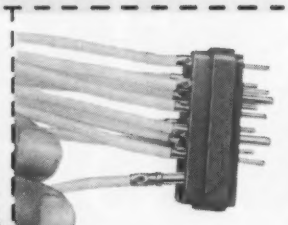
15 contact, multi-purpose connector. Mates with, or replaces existing solder connectors.



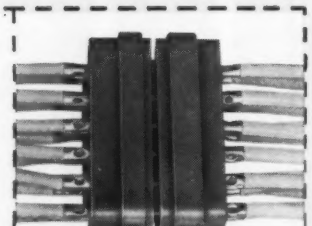
Feed-thru, modular design, multiple insert connector. 35 contact inserts, can be removed from frame for easy contact insertion or removal. 5 or 8 insert frames available.



CRIMP pins or sockets on wire



SNAP-LOCK contacts into plug or receptacle



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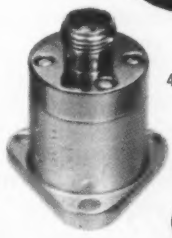

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by Dana A. Griffin
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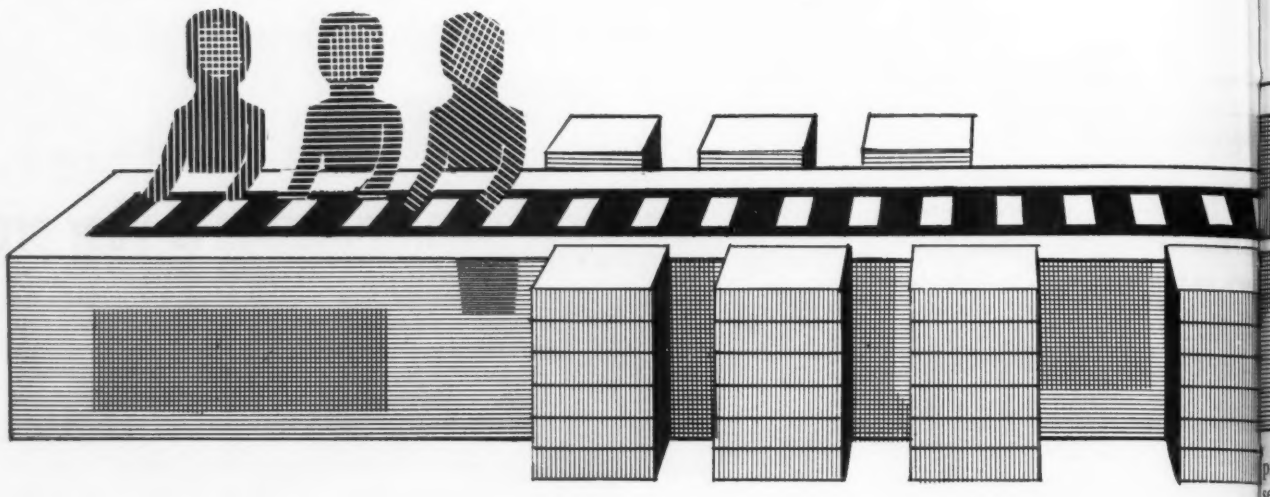


COST FACTORS
IN HIGH RELIABILITY ASSURANCE COMPONENT PART PROCESSING PROGRAMS

The statistical approach to reliability predictions of system performance has clearly indicated that the reliability of electronic components in a complex system must be increased beyond current reliability levels by several orders of magnitude. In addition, simple mathematical calculations demonstrate the need for an enormous increase in the number of parts that must be tested to prove that a given component part manufacturer's product meets the acceptable reliability level (ARL) required by a given system's reliability requirements.

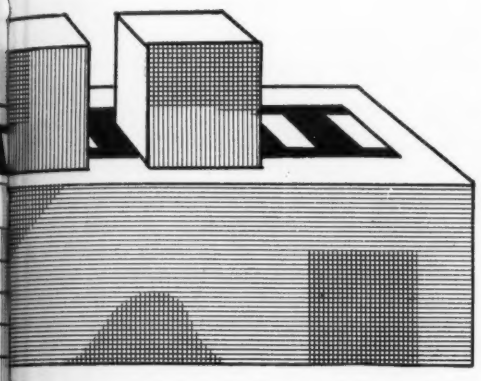
For many years an ARL of 1% was considered satisfactory as the majority of our military systems employed less than 1000 component parts with an early failure potential. Today, systems complexity has increased to the point where system reliability demands the attainment of a .1%, .01%, and even a .001% acceptable reliability level for component parts! This requirement automatically generates a need for facilities to test tens of thousands or hundreds of thousands of component parts simultaneously for 1000 hours or more, in turn calling for large, expensive test facilities and automatic high speed measuring devices which must operate at reliability levels unheard of a year or so ago.

A testing facility that will make 15,000,000 measurements in 1000 hours without a single error is a breath-taking goal, if one considers all of the potential points of failure in a system capable of testing 500,000 parts simultaneously. The size of such facilities and their operational reliability requirements demand a substantial investment of capital to obtain the desired end result. The purpose of this article is the disclosure of other cost factors which should be included in the evaluation of these unique programs.

We are in the process of passing from one era into another, insofar as the responsibility for financing advances in component part reliability is concerned. For a generation these improvements have been financed, in the main, by the large volume requirements of the radio and television industries for low-cost components that will provide an ARL of approximately 1%. Further improvement, with the inevitable increase in price, bars any desire for higher-quality components by this segment of the industry.

Despite the natural reticence of the military services to underwrite the cost of producing a family of components one hundred to one thousand times as reliable as their commercial counterparts, major investments for production and testing facilities must be made by the military services. To do otherwise would deny the validity of the entire concept of reliability prediction. A start on such programs is being made in several areas, but there is some evidence that the services may not get their money's worth because of the traditional tendency to trim proposed capital investments for the necessary facilities by the brute force percentage cutback method.

It is easy to demonstrate that this is a "penny-wise, pound-folish" approach to the problem and that other cost factors deserve far more attention than the initial capital investment for facilities. There is a significant difference between a conventional quality assurance program and the high ARL programs now getting under way. In a conventional program involving at the most a few dozen parts, the services of a single engineer are required to perform all of the necessary operations. Programs with targets of .01% to .001% ARL create a huge component part handling



program in which many thousands of parts must be assembled into test features, disassembled and re-assembled several times before they are permanently placed in a subassembly of a weapons system.

We have then a "quality assurance" program that has turned into a major "manufacturing" operation. It requires labor (time and motion), material handling (process flow) inspection, part identification, and includes several operations not found on a conventional production line. Every one of these operations cost money and the cumulative total of these operating costs represents a continuing expense of great magnitude, over a period of a year or more. It is extremely important therefore to look at operating expenses more carefully than the capital investment for facilities in programs of this type. If the processing system designer is not handicapped by a limitation on capital expense, he can effect great savings in the overall cost of processing a given quantity of parts through the system.

This can be demonstrated by use of the simple formula:

$$A/B + (C/B \times T/L) = M \qquad \text{Where:}$$

A equals annual operating expense.
B equals number of parts processed per year.
C equals capital investment for processing facilities.
T equals one year.
L equals life of the facilities in years.
M equals unit processing cost for each part.

Let us look at several examples on the basis of a one-year program and a ten-year facility life expectancy.

$\$500{,}000/500{,}000 + (\$1{,}000{,}000/5000{,}000 \times 1/10) = \$1.20$

In this example, more than 80% of the processing cost is chargeable to operating expense. Now, let us assume that by increasing the capital investment initially, we can introduce more automation and reduce component-handling costs substantially. We have:

$\$250{,}000/500{,}000 + (\$1{,}250{,}000/500{,}000 \times 1/10) = \$0.75$

In this example, the added capital investment can be written off in the first year of operation! These two examples have been cited to demonstrate the inter-relationship between operating costs and capital investment in high reliability component part processing programs. Realistic costs can be determined by a careful cost analysis of any proposed program.

OPERATING COSTS

There are four major operating cost areas which have the greatest effect on overall costs.

- Power and/or fuel costs.
- Assembly and handling labor.
- Testing and Data Recording.
- Data Reduction and Analysis.

POWER COSTS

Large-size installations can use more than 100 KW of electrical power continuously. This totals 876,000 KWH per year. Most of this energy is required to heat and cool environmental chambers. While an all-electric system is convenient, it is not necessarily the cheapest system to operate.

A dual system employing hot air from a hot-air furnace for the major portion of the required heat with auxiliary electrical heat for vernier control can be more economical. The forced air circulation system can also aid in cooling the chambers to the ambient temperature, thus reducing the power requirements of the refrigeration system.

Brine-cooling systems, or liquid CO_2 systems are more efficient and more reliable than the gas-compression systems generally employed for environmental chamber cooling and cost considerably less. Large-scale installations require a thorough analysis by industrial engineers to determine the best compromise between capital investment and operating costs. Both can be minimized by adequate design.

ASSEMBLY AND HANDLING LABOR

The costs of temporary parts-mounting and parts-handling are dictated to some extent by the requirements of the part-processing test specifications.

HANDLING OPERATIONS

Considerable savings can be effected by arranging the sequence of the tests to minimize assembly and handling labor. A loaded factory labor cost of two cents per assembly operation per part is conservative. We then have a cost per operation of $20,000 per million parts. One assembly and one disassembly operation are a minimum requirement, giving us a basic handling cost of $40,000 per million parts.

There are three ways that parts can be mounted for environmental testing. The first method is to mount the parts on modules which may hold from 50 to 200 parts. The modules are then moved to various test positions and into and out of environmental chambers. The second method is to mount the parts on fixed modules in a module-transfer cart that can be moved in and out of the chambers. The third method is to mount the parts on expendable printed circuit modules, which require additional soldering and inspection operations, and then transport these modules through the system.

The first method requires a substantial increase in the capital investment and introduces additional contact closure problems. The second method is the best compromise, as the capital investment for part-mounting fixtures is the lowest and only the minimum handling costs (2 operations) are required. The second method has one limitation. Inasmuch as the parts are connected to the test-switching system in the transfer cart, switch and wiring capacitance make it impossible to make high-frequency tests on the components when they are mounted in the cart.

The test sequence must be arranged so that high-frequency tests are made before or after the parts are mounted in th transfer cart. This limitation also applies to the first and second methods, except that these methods envision transfer of a loaded module rather than individual parts.

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Use of these methods introduces additional problems of module-handling, storage and identification of the modules.

To recapitulate, method #1 will require an additional capital investment for re-useable modules in the neighborhood of $100,000, plus a continuing maintenance expense for their repair.

Method #2 requires a relatively low-cost automatic feed system to the high-frequency test set, if one is required in the test procedure.

Method #3 requires the use of 5000 expendable modules per year at a cost of approximately $20.00 each (200 parts per module) for an operating expense of $100,000, plus the cost of at least 3 module-handling and identification operations. At a cost of $2.00 each, this represents an additional operating expense of $30,000.

We have then in an operation involving one high-frequency test sequence and a series of DC tests the following:

METHOD #1	
1. One loading and one unloading (individual parts)	$ 40,000
2. Three module transfer operations (15,000 @ $2.00)	30,000
3. Plus added $100,000 capital cost for modules	100,000
	$170,000
METHOD #2	
1. Three loading and unloading operations of individaul parts	$ 60,000
METHOD #3	
1. Loading 5000 expendable modules @ $20.00	100,000
2. Three module transfer operations (15,000 @ $2.00) ...	30,000
	$130,000

TESTING AND DATA RECORDING

In a program involving one million parts, ten sets of measurements during a 1000-hour test period may be required. If five tests are made on each part, we are confronted with the task of making and recording 50,000,000 measurements a year. Two expensive classes of labor are involved in this operation: technicians and engineers. The measuring devices must be fail-safe, the recording devices must be exceptionally reliable; and these two inseparable types of apparatus must operate at very high speeds. Here, speed of operation will determine the number of test sets required and the number of people required to operate them, assuring fully automatic operation. If human intervention is required, the number of people will increase very rapidly and the speed of operations will be drastically reduced.

We must assume that a 3-shift, 7-day week operation is required where environmental tests are involved. This further enhances the importance of labor costs due to overtime, premium weekend pay, etc. If we assume that two fully automatic test set-data recorders are sufficient, two technicians per shift will be needed for a total of 312 man-weeks per year. At a loaded rate of $300 a week, we have an operating labor cost of $93,600 per year.

If limitations are placed on the investment for test sets and data recording equipment which reduce its speed of operation, or require action by an operator, the force of technicians can easily double, triple. or quadruple. It becomes obvious that increasing the investment in test sets and data recording systems from $50,000 to $150,000 will be wholly justified in a one-year program where the number of technicians required per shift can be reduced by as few as two technicians per shift.

DATA REDUCTION AND ANALYSIS

Two expensive classes of labor are required in these operations: technicians and mathematicians. Large numbers of punched cards and various types of tape must be handled in this operation and the machines must operate at very

Continued on page

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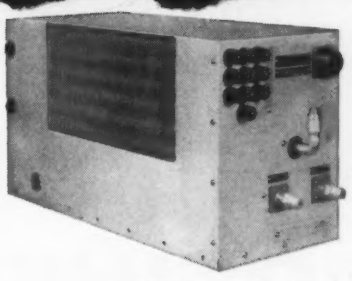

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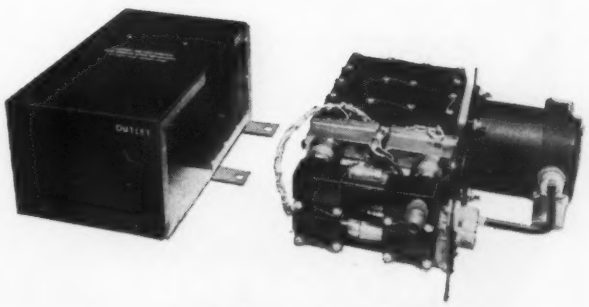

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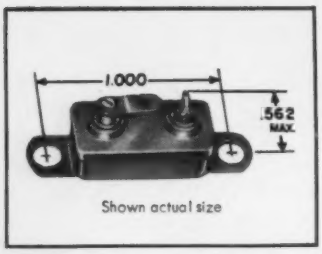

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CIRCLE 6 ON INQUIRY CARD

high speed without error. Flexibility is also important as several types of analysis will be needed.

Here again, the number of people required will depend to a large extent on the speed and degree of automatic operation that the data reduction machines afford. An investment for high-speed equipment will eliminate a need for 3-shift operation and thus effect a large reduction in operating costs. If two technicians are required on a single-shift basis, operating costs can be dropped from $93,600 per year (3 shifts) to $30,200—a net saving of $63,400 per year.

Operating flexibility and speed can also reduce labor costs in the area of data analysis. Loaded labor rates per man can run in excess of $15,000 per year in this area of activity.

CONCLUSION

Continuing programs for large-scale equipment processing will be required as long as there is a need for parts that meet acceptable reliability levels of 0.1% or more. Even if capital investments for facilities are written off in five years, operating expenses are the predominant factor in overall costs per processed component. They become even more important if a realistic equipment life expectancy of ten years is used in determining costs.

The number and type of assembly and handling operations, plus the speed and degree of automatic operation of the test equipment, data recording and data reduction machines are the major factors that must be considered.

They can be minimized by sound processing system design, when arbitrary limitations are not placed on the capital investment for the facilities required to meet the test specifications.

For a brochure on equipment for component reliability testing:
Circle No. 79 on Inquiry Card

Epoxy-Coated Precision Film Resistor

New epoxy-coated precision film N-Style resistor, produced in ½ and ¼ watt sizes, provides excellent insulation and moisture resistance and is expected to have wide application in transistorized circuitry. Price will be competitive with molded, deposited carbon units. Both resistors are dip-coated with a new epoxy, developed to provide moisture resistance and insulation surpassing requirements of the military specification. The coating will withstand chlorinated hydrocarbon solvents used in cleaning flux from printed circuit boards. Corning Glass Works, Corning, New York.

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Light-Sensing Photo-Duo-Diode

A new subminiature light-sensing photo-duo-diode is claimed to have sensitivity on the order of four times that of any other photosensitive unit. The single-ended glass case measures 0.500 inch by 0.085 inch in diameter. A minute glass lens is located at the end opposite the leads. Known as the 1N2175, the new N-P-N diode passes up to 1200 foot-candles of light. In darkness, the 1N2175 will pass less than 0.5 microamps. Dissipation is rated at 250 milliwatts at 25C and any biasing voltage up to 50 volts will operate the device. It will operate equally well on either alternating or direct current, and is derated to 125C with a minimum operating temperature of −55C. Texas Instruments, Inc., Dallas, Texas.

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CIRCLE 7 ON INQUIRY CARD

CONTROLLABLE INDUCTOR CHARACTERISTICS

Ranges of Performance Attainable

Equipment designers are finding more and more applications for controllable inductors where such things as rapid response, remote control, complete flexibility of control characteristics, or large inductance range with absence of moving parts are desired. The applications are limited only by the ingenuity of the designers.

Here is an up to date account of these devices based on information obtained from H. F. Spirer, Assistant Chief Engineer at CGS Laboratories, Inc. We asked him:

How are controllable inductors made? What are the ranges of their important performance characteristics? What are some of their most effective applications?

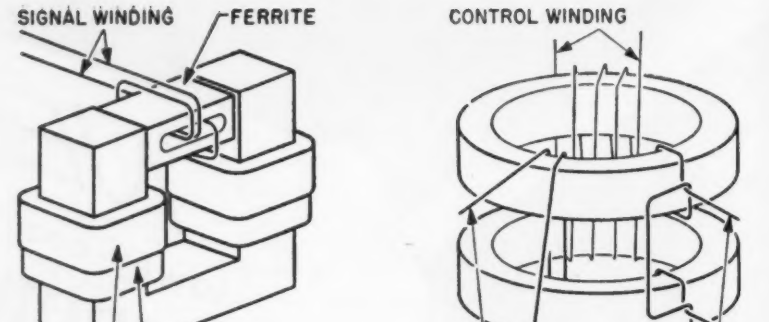
CONSTRUCTION

To make a controllable inductor you first wind a coil, called the signal winding, on a toroidal core of ferritic or powdered iron material, which has a permeability several times greater than air. The core, of course, increases the inductance of the coil for a given number of turns. You then wind another coil called the control winding on this same toroid. Now by passing a direct current through the control winding you can change the signal inductance. The direct current sets up a flux in the toroid, changing its permeability. Since the signal winding is wound on the same toroid, its inductance changes in proportion to this incremental permeability.

You have now made a very useful controllable inductor. If you want to sweep an oscillator, you can connect the signal winding in place of the tank inductance and put an appropriate sawtooth current in the control winding.

A third winding, called the bias winding, is sometimes an advantage. It acts as a junior control winding for use in setting an operating inductance, or in dual control schemes where both the control and bias windings may perform independent control functions. For some applications you can use a permanent magnet to obtain the bias control field.

Inductance change ratio is an important concept in dealing with these units. It is a measure of how much change of signal inductance can be effected by going from near zero control current to the saturated state of the core. Inductance change ratio generally refers to the ratio of some starting inductance which will be large, to the saturated inductance which, in general, will be rather small.



Higher Frequency Units — Lower Frequency Units

FIG. 1. Typical Core Configurations

Before any appreciable field has been applied to the controllable inductor, its ferromagnetic core is in a "virgin" state, a state it will never again be in after the field is applied. If you apply a d-c field to the point of saturating the controllable inductor and then reduce this field to zero by reducing the current to zero, the inductance will be at the state called, "residual", because some residual flux will be left in the core. The residual inductance is less than virgin inductance because the d-c field reduces the permeability of the core.

Residual is a poorly defined state. One unit may be in a residual state as a result of applying one hundred mils control current and another as a result of two hundred mils. To simply say "residual" has little meaning. Specifying the saturation current is also insufficient because residual flux left in the material is a function of how the control current is varied. For example, residual inductance changes when the control current is recycled.

To use a standard starting point, engineers generally rate a controllable inductor by the demagnetized signal inductance. Demagnetization is achieved by putting a saturating alternating current through the control winding and reducing the amplitude of this current slowly down to zero. In most cases, when engineers talk of inductance change ratio they mean the ratios of demagnetized to saturated inductance.

RANGES OF CHARACTERISTICS

The ranges of important characteristics that have been realized in practical controllable inductors are very broad. Units have been constructed with starting signal inductances from 0.01 μhys to 10 hys, and have been used at frequencies to 500 Mc.

The largest inductance ranges, 400 to 1, are obtained with units useful at audio frequencies. As the frequency of operation is increased, the available inductance range decreases as a result of core-material and stray-parameter limitations. However, standard units now in production give inductance ranges of 3:1 around 300 Mc. Laboratory units have been made with 4:1 inductance range around 400 Mc.

Starting Q, another important signal parameter, is around 80 to 120 at low audio frequencies and tends to rise as the frequency increases to about 250. It then drops to the order of 5 to 10 at 400 megacycles. In using the controllable inductor, keep in mind that the Q is not simply a function of starting frequency, but also varies with signal inductance and applied frequency. For large signals it is also possible that signal amplitude will affect Q. Plots of the surface formed by Q in inductance-frequency space, called Q maps, are useful in design (See figure 2).

Some general principles can be used as a rough guide to Q variations. At low frequencies, because the series copper losses predominate, Q will in general drop as frequency of operation is increased by increasing control current. At fairly high frequencies—above 80 megacycles—core losses predominate. The effect of these losses is to make Q rise with frequency and increasing control current. A typical variation of Q with frequency in the 100 to 150 megacycle range will be from 25 at 100 megacycles to 130 at 150 megacycles.

Control power required to obtain the inductance ranges previously stated is around 1/100 to 10 watts. Less range can be had with expenditure of less power. The controllable inductor, being a current sensitive device is generally controlled from a current source, ranging from 10 to 150 mils. Typical

control resistances are 100 to 1500 ohms. Control inductances have varied from less than 100 millihenries to 100 henries. Wherever control inductance becomes a problem, it can be reduced by increasing the number of turns thereby increasing the control current required.

Temperature coefficient of a controllable inductor depends on the characteristics and configuration of the core material and signal winding characteristics. Most controllable inductors have larger temperature coefficients than do linear components. In many controllable inductors the temperature coefficient is a function of the state of saturation. The temperature coefficient of inductance will go from a negative value to a positive value as the control current is increased. Obviosuly, the best quiescent point to operate the unit is where the temperature coefficient passes through zero. Knowledge of this characteristic can help in obtaining the minimum possible temperature coefficient. Typical values of temperature coefficient are from 0.01% to 2% per degree C change in inductance. Fortunately, the characteristics are uniform in controllable inductors of the same type.

If we build a controllable inductor in the manner described earlier, it will have transformer characteristics. Alternating current present in the signal winding will produce ac in the control winding. For this reason we very rarely build controllable inductors that simply. Instead, the signal winding is balanced with respect to the control winding so that the coupling between them is greatly reduced. Coupling can be kept below −40 db; units have been built where it is below −60 db.

The distributed capacitance of the signal winding, which depends greatly on the nature of the signal winding, varies from over 60$\mu\mu$f at audio frequencies to less than 1 $\mu\mu$f for units useful at VHF.

Power handling capabilities of the signal windings of controllable inductors reach hundreds of watts.

Speed of response is primarily limited by the control winding. Circuits have been made with speed of response measured in microseconds. To obtain short response times, reduce the number of turns on the control winding. This reduces the control inductance and increases the control current required. The control winding should be driven from a constant current source.

Like all ferro-magnetic devices, controllable inductors have hysteresis. The amount of error in frequency resulting from hysteresis varies from ½ to 10%; varying both with unit and with point at which it is measured.

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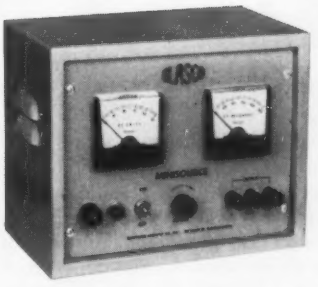

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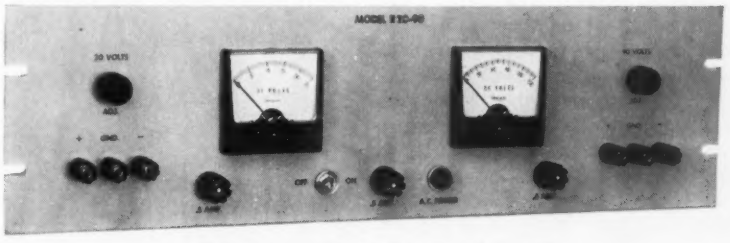

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Cast aluminum gear cases for jet aircraft starters are machined and assembled at The Black Rock Manufacturing Company, successor to Reed-Prentice Corp., Bridgeport, Connecticut. The 98 studs used in the unit are treated with LOCTITE Sealant to secure them against vibration. The jet starter units receive an input of 2500 rpm and develop output of 5000 rpm to each of three flexible shaft connections. LOCTITE was selected for this application since it provides a greater prevailing torque than any mechanical locking device. The locking strength of LOCTITE is not affected by the wide temperature ranges the unit encounters in arctic to tropic operation.

Stud thread is hand-dipped in shallow tray of Loctite, then positioned in casting for tightening. Three sizes of steel studs are used: ¼"-20, ⅜"- 18 and ⅜"-16.

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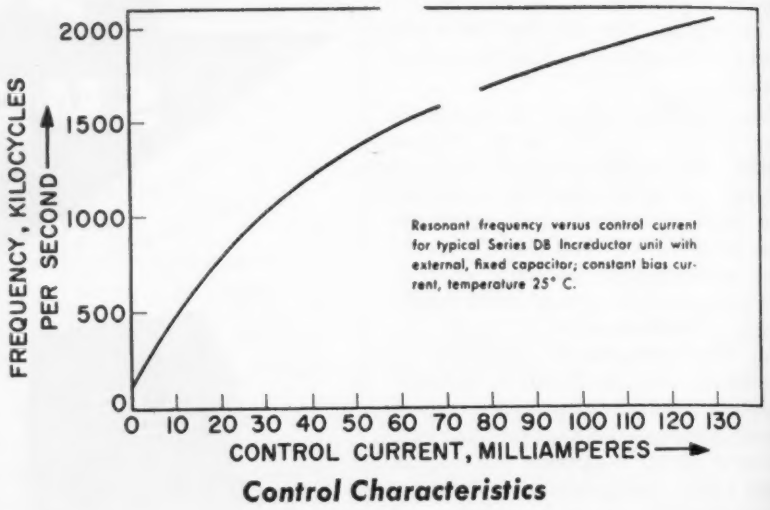
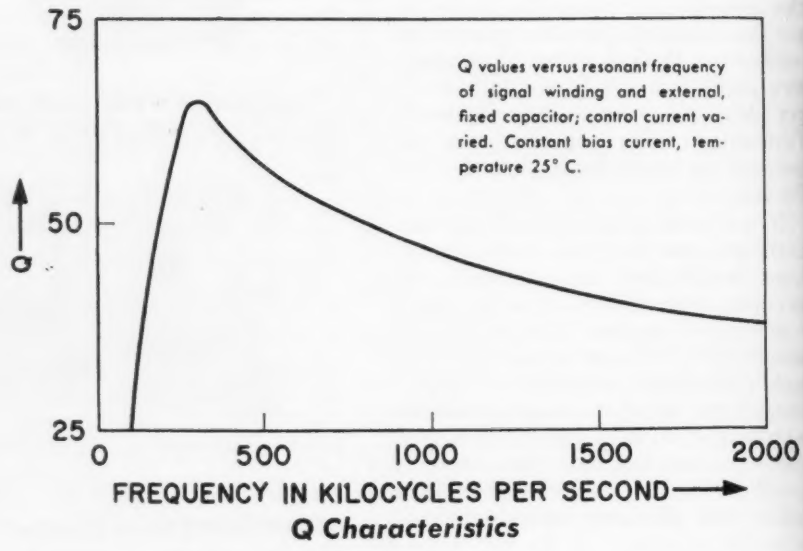
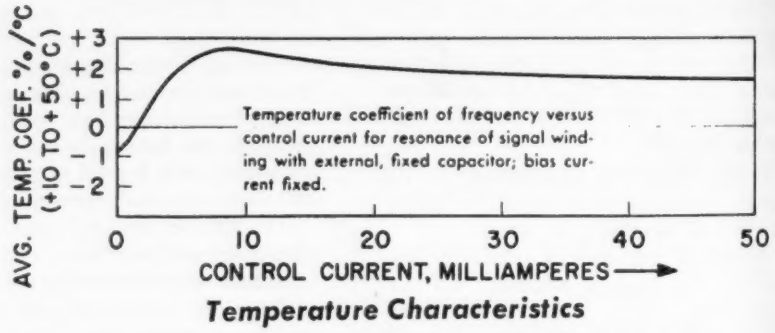

FREQUENCY, KILOCYCLES PER SECOND
2000
1500
1000
500
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130
CONTROL CURRENT, MILLIAMPERES
Resonant frequency versus control current for typical Series DB Incroductor unit with external, fixed capacitor; constant bias current, temperature 25° C.

Control Characteristics


Q
75
50
25
0 500 1000 1500 2000
FREQUENCY IN KILOCYCLES PER SECOND
Q values versus resonant frequency of signal winding and external, fixed capacitor; control current varied. Constant bias current, temperature 25° C.

Q Characteristics


AVG. TEMP. COEF. %/°C (+10 TO +50°C)
+3
+2
+1
0
−1
−2
0 10 20 30 40 50
CONTROL CURRENT, MILLIAMPERES
Temperature coefficient of frequency versus control current for resonance of signal winding with external, fixed capacitor; bias current fixed.

Temperature Characteristics

FIG. 2. Typical Characteristics, Low Frequency Controllable Inductor

Hysteresis and temperature are serious problems; yet they are the ones most easily and most commonly overcome. Either temperature coefficient or hysteresis effect can be reduced by selection of a suitable operating point. Hysteresis is less at near zero or maximum control current. Some units can be operated near the zero temperature coefficient region. In addition, many tricks of circuitry can be used to eliminate hysteresis and temperature effects.

APPLICATIONS

A very frequent application of controllable inductors is in panoramic receivers in which LO and RF are both swept in synchronism across the band to be surveyed. Receivers of this type are practical for frequencies from audio to 400 Mc. Typical ranges covered by such receivers are 25 to 80 megacycles, 100 to 160 megacycles, 130 to 200 megacycles and 200 to 333 Mc.

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CIRCLE 10 ON INQUIRY CARD

Another application of controllable inductors is as antenna switches (to connect or disconnect a receiver from an antenna, to connect a transmitter and receiver alternately to an antenna, or to alternately connect different receivers to one antenna) where switching has to be performed rapidly. Such a switch has been made with more than 40 db attenuation in the off position, a transmission loss of less than ½ db in the on position, and switching rate of 2800 cps. Considerable increase in switching rate is feasible. The switch is a low pass filter in which the inductive elements are all controllable inductors. It is designed so that, when the controllable inductors are saturated and therefore have minimum inductance, the cut-off frequency of the filter is higher than the highest frequency to be transmitted. When the controllable inductors are not saturated, their inductance rises and the cut-off frequency of the filter drops below the lowest frequency of the desired transmission band. These devices have been used for receiver-transmitter switching to a single antenna with transmission powers in the order of over 100 watts and a receiver sensitive to 0.2 micro-micro-watts.

The controllable inductor is especially well suited for use in sweep generators. A typical sweep generator of this type is commonly available in kit form. The controllable inductor is responsible for the low cost of such kits. The typical oscillator has 4 or 5 bands, from 0.5 to 200 Mc., obtained by using separate cores with a transformer iron yoke carrying the control winding. Typical sweep ranges are 4-10 Mc, 10-30 Mc, 30-80 Mc and 80-220 Mc. The oscillator is amplitude controlled, delivers one tenth of a volt to a 50 ohm load, and is swept at line frequency rate.

Controllable inductors have been used for frequency modulation, especially in telemetering where space is a tight requirement and extremes of temperature are likely. Often the effect of temperature is reduced by putting a thermostatically controlled heater in the controllable inductor can. In most cases this does not change the can size and greatly reduces the effect of ambient temperature variation.

Controllable inductors have also been used as the variable inductor in analog computers. They have been used in antenna tuning elements. Filters with variable bandpass and/or center frequency and variable delay lines have been constructed using controllable inductors.

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Slippery Tables

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Vibration Manual

The "Vibration Manual for Engineers," 2nd edition, a Navy publication containing formulas useful to design engineers in minimizing mechanical vibration difficulties, is available through the Office of Technical Services, U. S. Department of Commerce. The manual was prepared by the Structural Division of the Navy's David Taylor Model Basin. It is a revision of an earlier manual with the same title issued in 1944. Most formulas conform with a notation based on the inch-pound-second system of units. They are presented in case form and are illustrated and explained. The manual contains 32 pages and price is $1.00.

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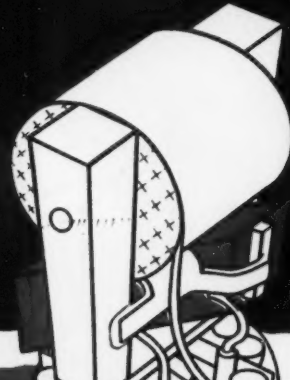

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POTENTIOMETER SPECS FOR SEVERE ENVIRONMENTS

George Mucher,
Executive Vice President
Clarostat Mfg. Co., Inc.

As with practically all components of modern military systems, reliability requirements for the precision potentiometer have become markedly more severe in recent years. Because of the importance of its function, and its widespread application as one of the most flexible of the precision components used in modern control and computer systems, the precision potentiometer necessarily bears the brunt of the vastly increased emphasis on reliability. Units of accuracies comparable to the laboratory secondary standards of only a decade ago must now maintain their built-in precision over the temperature, shock, and vibration extremes called for in new space applications. To top it off, nuclear radiation, which has a notorious way of deteriorating certain critical materials, has introduced a completely new set of problems.

Unfortunately, the very adaptability of the precision potentiometer to diverse applications has slowed down attempts at standardization, both in terms of performance, and environmental requirements. The few specifications available never seem entirely suitable for a specfic severe application. The usual procedure is for the project engineer to synthesize his own specifications by referencing selected paragraphs of existing "standard" specification, adding the particular requirements appropriate to his own application, to prepare a "composite" component specification against which he can place his purchase order.

A precision potentiometer is a complex device to specify completely. You have to be a specialist to prepare a really good specification with no more than a few loop holes. With more specialized potentiometer types, such as metal or carbon film units, for example, even the experienced specification writer may encounter items (granularity, and severe limitations on wiper current, such as to prevent an ohmmeter check, for example) that are new to him. In such instances, a program of self-education should supplement the usual negotiations with the manufacturer, to guarantee a realistic specification.

Even the simplest specification, if it is reasonably complete, taken together with *all referenced* requirements, will represent a complex document. In any specific application, it is often impractically time-consuming and costly to go through the complete tests, guaranteeing by direct check, every performance and environmental requirement of the particular model and type in question. Furthermore, it must always end up as a matter of judgment as to how many units to test, in what sequence and "natural combination" of environments, to reflect most accurately the anticipated operating conditions.

The best answer to the dilemma again lies in the accumulated experience of the potentiometer manufacturer. Over the years, he has been constantly evaluating the reliability of his product. Field reports from satisfied and dissatisfied customers have been reflected back to his engineering and production departments, quality control, and even his vendors. Process specifications have been re-written to approach near-perfection.

During the course of production, environmental tests are run *on almost a continuous basis,* checking one point or another, and gradually building up the company's store of information on what does and does not work. In particularly important applications, where funds are allocated in advance, fairly complete environmental tests may be run on specific models, the results of which may be applicable to the company's entire line. Often, a large customer, or the government will conduct these tests as part of an evaluation or comparison of manufacturers. A drawerful of test reports, thoughtfully interpreted on a continuous basis in terms of the company's product line, is the strongest assurance of quality.

A word might be said here about vendors, even the most progressive of whom are much more optimistic of their products, especially the new developments, than are the customer-manufacturers. To resist their glowing descriptions of bearings, lubricants, materials, and finishes which (in their laboratory) solved all environmental difficulties, requires a considerable experience with "unexplainable" failures, which are understood perhaps years later as theory is developed.

The progressive manufacturer, many years in the business, is in a key position to evaluate a design environmentally, particularly with respect to the newest specifications. He knows what he can do, and instantly recognizes the points of uncertainty in a new specification. This permits immediate concentration on these points by him and his customer. Tests and past history can be scanned for pertinent results. Long-term testing can be started at once. Environmental studies need *only* be made in the limited sphere of uncertainty, with a more cursory review of the "routine" paragraphs. Often, it is acceptable to refer to specifications previously met on sufficiently similar units that have been more completely evaluated. In some instances, following a proven design procedure is enough to win acceptance. For example, fungus testing is usually waived on the certification that all materials in the unit were either non-nutrients for fungus, or else protected by standard fungus-protective coatings.

"13 Outstanding American Designs"

New booklet featuring contest winners has just been published by the manufacturer of Mars Pencils, sponsor of the annual Mars Outstanding Design Contest. The booklet contains photographs of prize winners, through 1958, along with pictures and descriptive text of their design. J. S. Staedtler, Inc. Hackensack, N. J.

Circle No. 155 on Inquiry Card

Plastic-Impregnated Bearings Need No Lubrication

A bearing made of fabric impregnated with Bakelite phenolic plastic eliminates need for lubrication of bearings in mechanical applications ranging from miniature instruments to hydroelectric stations. In some instances, such bearings have outlasted the life of conventional metal bearings by as much as eight times. Ruslon bearings, as they are called, can replace many conventional metal-to-metal bearings, which must be regularly serviced with grease or oil. The combination of Bakelite phenolic and fabric supplies strength in a permanently infusible form. In addition, the phenolic is lightweight, resistant to high temperatures, dimensionally stable under most atmospheric conditions and has a low coefficient of friction. The bearings are inert to acids and alkalies and are not subject to electrolysis or corrosion by salt water. Union Carbide Plastics Co., New York, N. Y.

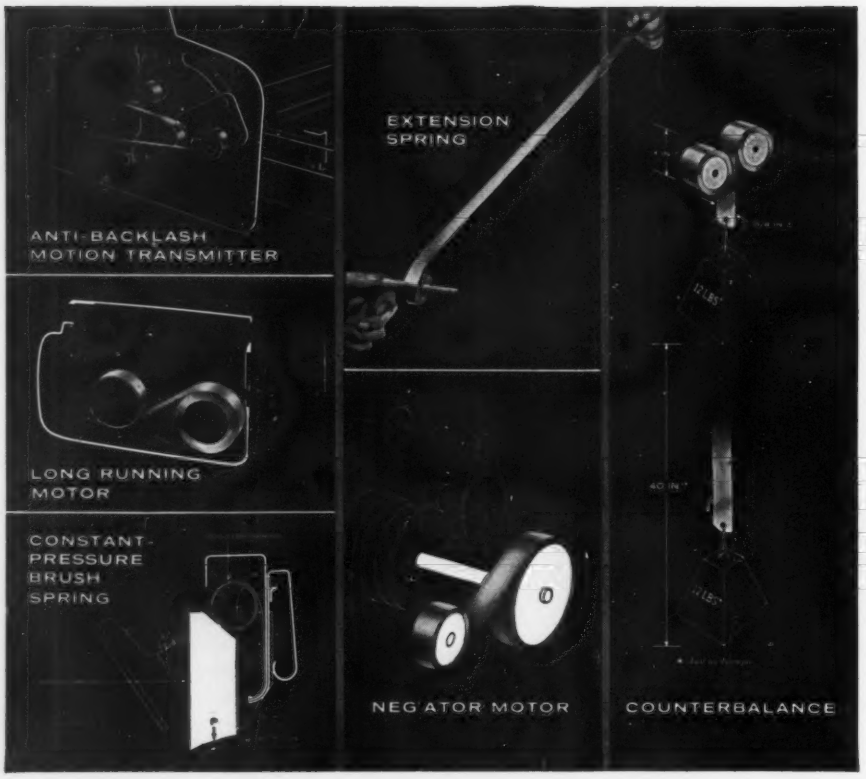
Circle No. 216 on Inquiry Card

Potentiometer Definitions

Brochure entitled "Potentiometer Definitions" lists functional definitions which are applicable to wire wound and composition controls, thus avoiding misinterpretation of terminology between supplier and buyer.

Source: Clarostat Mfg. Co., Inc.
Dover, N.H.

For your copy: Circle 176 on Inquiry Card



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Circle No. 160 on Inquiry Card

Vibration Exciter

Vibration exciter used for conventional sine wave testing, or for the newer random or complex motion techniques, provides in the same size unit up to 40 percent more force output for more efficient utilization of power amplifier output. Unimode suspension, an MB development, provides a one-inch double amplitude for continuous duty vibration testing. The exciter is liquid cooled for environmental test chamber applications in ambient temperatures from −100 to 300 F, and at altitudes up to 250,000 ft. The new exciter has a vector force output of 10,000 lb., and a frequency range of 5 to 2,500 cps. Weight of the moving element is less than 100 lb., its axial response is well above 2,500 cps. MB Mfg. Co., Div. Textron, New Haven, Conn.

Circle No. 206 on Inquiry Card

Size 8-Resolvers

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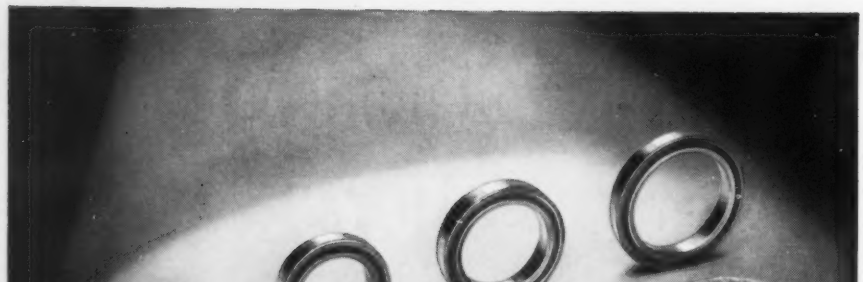

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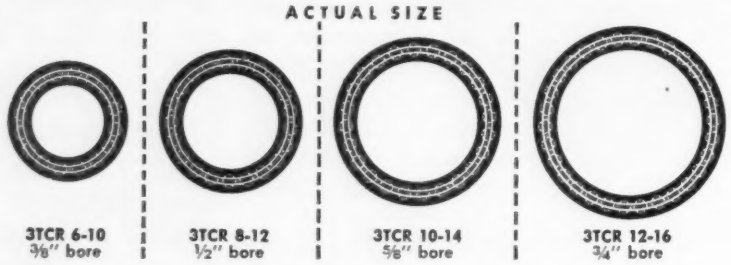

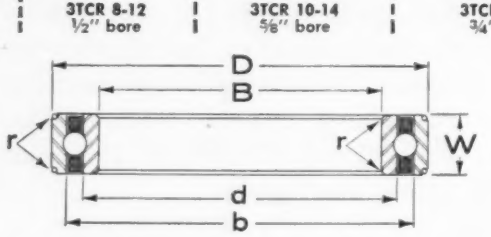

*B bore ± .0002	*D o.d. + .0000 − .0004	W width + .0000 − .0050	†r radius	b outer land ± .001	d inner land ± .001	Balls no.	Balls size	‡L lbs.	§S lbs.
.3750	.6250	.15625	.010	.542	.457	16	1/16	77	110
.5000	.7500	.15625	.010	.672	.587	21	1/16	89	144
.6250	.8750	.15625	.010	.797	.712	24	1/16	94	165
.7500	1.0000	.15625	.010	.922	.8375	30	1/16	101	206

Dimensions are in inches. *Tolerances shown are for Precision Grade. Write for Ultra Precision Grade tolerances. †r is maximum fillet radius on shaft or housing that bearing will clear. ‡Radial load capacity at 500 rpm and 2500 hours average life. §Static non-Brinell load capacity.

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Circle No. 175 on Inquiry Card

Electronic Switch Tubes

Fast-switching cold-cathode trigger tubes replace relays, thyratrons and other devices in simplified circuits for reliable military and industrial equipment. Designed to operate under extreme conditions of heat, shock and vibration, these rugged tubes control up to 500 amperes with input currents of less than 20 microamperes. Operating ambient temperature range is −55C to +85C. Including miniature and subminiature types, this line has anode delay times from 1.6 to 4.0 microseconds with a maximum variation of 0.4 microsecond. Minimum trigger voltage for a two-microsecond pulse is 230 volts. Hold-off voltages range from 1000 to 3000 volts. CBS-Hytron, Newburyport, Massachusetts.

Circle No. 110 on Inquiry Card

Digital Recording System

Digital logging system, designed to provide a digitized output from potentiometer recorders to shaft inputs, eliminates logging of recorder readings and transcribing of strip or circular chart recordings. Evolved from the growing need to reduce data at a fast, accurate rate this unit automatically records data at unattended stations at precise intervals by the addition of an external timing device; can be used for laboratory and production tests, maintenance checks, instrument calibration, and anywhere a recorder or shaft rotation exists. The system is supplied as a ready-to-operate unit, complete with all necessary cable interconnections and encoder mounting hardware for easy installation. No gearing is necessary between encoder and instrument drive. Datex Corp., Monrovia, Cal.

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Differential Pressure Transmitter

Differential pressure transmitter features 0.2% measurement accuracy, infinite resolution, and zero output preset at any point throughout the range. With a sensing element which is a differential transformer with a built-in demodulator for d-c outputs, the unit has a differential sensitivity of one part in 1000 or better. The shock resistant unit is suitable for corrosive atmospheres and available in static pressure ranges from 0-100 to 0-300 psi with differentials up to 100% of range. International Resistance Co., Computer Components Div., Philadelphia, Pa.

Circle No. 200 on Inquiry Card

High-Temperature Torque Motor

Torque motor, which can operate at temperature of 600 F, permits the use of electrohydraulic or electropneumatic servovalves or similar devices in high-temperature applications without the need for complicated cooling systems or thermal lag provisions. The unit has a midposition force of over 8 pounds, a stroke of ±.008 inches at a radius of .750 inches. Measurements: 1⅛ x 1-11/16 x 1¾ inches, weight: 10 ounces Only 4 watts of input electrical power required. American Measurement & Control, Inc., Waltham, Mass.

Circle No. 151 on Inquiry Card

Low-Level Input Transistor

A new silicon transistor operates at starvation current in d-c amplifier input stages. Recommended for use in the 2-200 microamps range, the transistor features drift of only .05 milli-microamps per degree C and .5 milli-microamps per day, making it useful in circuits with high impedance sources: phototubes, G-M tubes, infra red tubes and ionization guages. The high beta (typically 25 at 5μ to 70 at 100μ) and the extremely low ICO make possible many new low-current applications. Transitron Electronic Corp., Wakefield, Mass.

Circle No. 129 on Inquiry Card

Dual Feed Horn Provides Same Center of Radiation

A dual polarized feed horn for large size waveguide having two waveguide inputs provides the same center of radiation for both signals. Maximum power transmission is obtained in both polarizations. The horn handles 10 kw with more than 30 db decoupling between the signals, and is available in several frequencies. D. S. Kennedy & Co., Cohasset, Mass.

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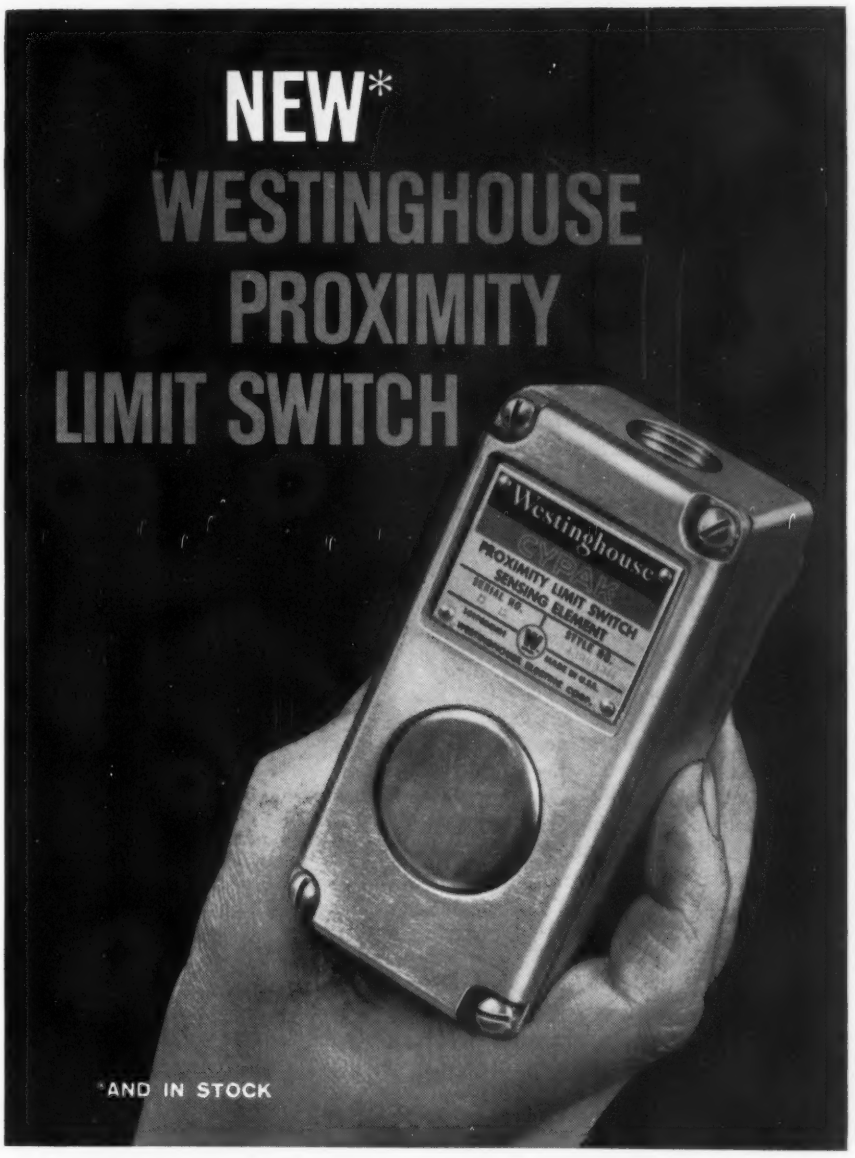

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RANDOM WAVE VIBRATION SYSTEMS

Ray L. Reid, Asst. Chief Eng.
Ling Electronics, Inc.

New Instrumentation and Techniques For Simulating Severe Vibration Environments

Early vibration testing employed sine wave forces exclusively except where a definite force-time history was required such as in the case of shock loads. Aircraft equipment and most industrial equipment were tested by sine wave techniques since forces experienced by the equipment were due in most part to vibration forces caused by rotating or reciprocating members. In aircraft the majority of the vibrations were the result of forces induced by rotating and reciprocating elements of the engine. Industrial machinery also were subject to vibrations induced by rotating and reciprocating elements of engines, motors, and actuating mechanisms.

Vibration testing consisted of duplicating this sinusoidal vibration and determining the response of components to be subjected to the environment. In most cases linearity of response was assumed and superposition techniques were used to determine the response to forces of different frequencies.

Where sinusoidal vibrations are dominant, these techniques are still employed. Sine wave testing is still the main method of determining structural modes and control system response.

Recently, however, the nature of the environment encountered in high performance aircraft and missiles has placed random vibration forces in the dominant position. These random forces are largely the result of aerodynamic turbulence and power plant fluctuations. They have random characteristics and cover a fairly wide bandwidth. The feeling among test engineers is that a true indication of the response of individual components or complete systems to a random wave environment cannot be obtained by a superposition of the response to forces at particular frequencies within the bandwidth. This is largely due to factors of non-linearity in the response of the system elements. This non-linearity factor can make the element and the system sensitive to any of the characteristics of the force . . . magnitude, frequency, or rate of change of frequency. As a result, the trend in vibration testing of equipment subject to random force environments is to duplicate the environment as closely as possible in order to obtain the response to every aspect of the environment.

Naturally, there is some controversy involved. Some test engineers firmly believe that comprehensive sine wave testing is still sufficient. Othere are firmly convinced that for a random environment only random wave testing can give conclusive proof of the equipment's ability to survive. However, the large amount of random wave equipment being ordered by manufacturers

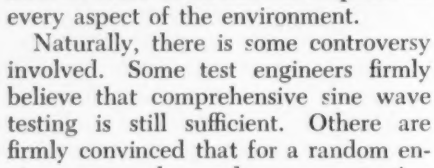

FIG. 1. Power Spectral Density plot shows acceleration density as a function of frequency. Random characteristics require this statistical representation of forces.

in the aircraft and missile fields is indicative of the growing interest in random wave testing.

The prime source of difficulty in the handling of random vibration is, of course, the very "randomness" of the vibrations. Random wave vibrations may be considered as having finite bandwidth but amplitudes that exhibit statistically random characteristics as a function of time. As a result, it is impossible to describe the amplitude of any of the frequency components positively at any one time. Rather, statistical analysis is employed to describe the characteristics on a probability basis. That is, the probability that any one amplitude can exist at any one specific instant is determined on the basis of a statistical averaging process.

Random wave vibrations can be plotted as a function of frequency by employing the Power Spectral Density curve. This is a plot of amplitude versus frequency where the amplitude characteristics have been determined statistically. The amplitudes for each frequency are examined statistically and their root-mean-square value determined. This value is used to determine the acceleration density defined by the following equation:

$$A = \underset{F \to O}{\text{Limit}} \; [a^2/F]$$

where:

- a is the root-mean-square value of the vibrations
- F is the bandwidth of the vibrations
- A is the acceleration density in g^2/cps

The density function plotted versus the frequency spectrum of the vibrations is the Power Spectral Density curve. Typical of random wave characteristics is the Power Spectral Density plot shown in Figure 1.

White noise which has the special characteristic of equal acceleration density at each frequency has the flat Power Spectral Density curve shown in Figure 2.

Describing random vibration requires that the frequency spectrum and the shape of the Power Spectral Density curve be given. In addition, the total root-mean-square vibration level of the spectrum may be determined by the formula:

$$A_{rms} = [\Sigma f^2_{f1} \; (A\Delta f)]^{1/2}$$

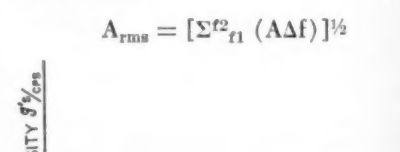

FIG. 2. Power Spectral Density plot of white noise is horizontal line indicating random variations with equal density at all frequencies.

Requirements for random wave testing have dictated the development of high performance equipment with capabilities to duplicate the vibrational environment with extreme fidelity. Not only must each frequency component be reproduced accurately, but the exact relationships between each of the components must be maintained.

To accomplish these tasks, provisions must be made in the equipment to compensate for any and all resonances that might influence the final value of forces applied to the component under test. This equalization of the test equipment insures that the component under test is vibrated in accordance with the Power Spectral Density curve chosen as specification for the tests.

Naturally, there are certain limitations to the amplitude of forces possible. A Gaussian distribution implies probability that amplitudes of unlimited value exist. Standard working procedure is to provide the system with capability of furnishing amplitudes equal to three times the r. m. s. amplitude. This factor is defined as the Crest Factor. A value of three is used since statistically 99.7 percent of the time actual forces would be below three times the r. m. s. value.

Since the requirements for random wave testing are far more rigid than those for sine wave testing, equipment developed for random wave studies are quite adequate for sine wave testing. In fact, the trend in the industry has been to procure random wave equipment because it has both capabilities.

Figure 3 is a functional block diagram of a typical vibration system with both random wave and sine wave capabilities. Noise generators, sinusoidal signal generators, and magnetic tape reproduction equipment can be used as the source of vibration signals. In a great many instances the vibrational environment comprises sinusoidal loads superimposed on a white noise spectrum. To duplicate this condition an electronic mixer is employed to mix the chosen sinusoidal signal with the output of the noise generator. To insure that the correct relationship is maintained between the two signals a servo system with feed back signals from the shaker is used to monitor and adjust the amplitude of the sine wave oscillator.

The first graphic equalizer and the band pass filter shape the output of the noise generator to the Power Spectral Density specified. This first shaping does not take into consideration any effects of the shaker or other elements of the testing system. Development of

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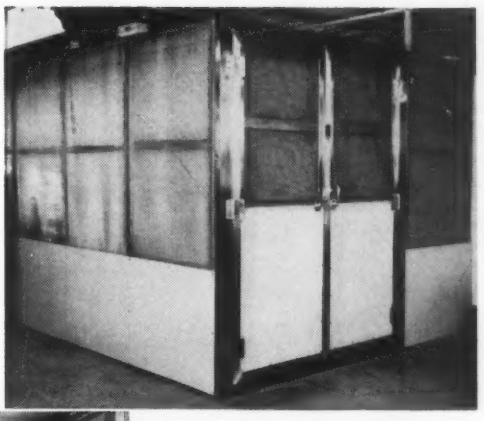

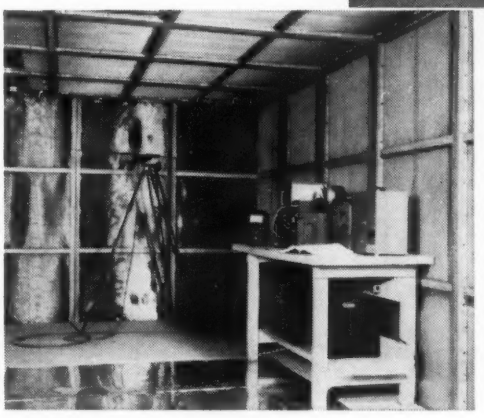

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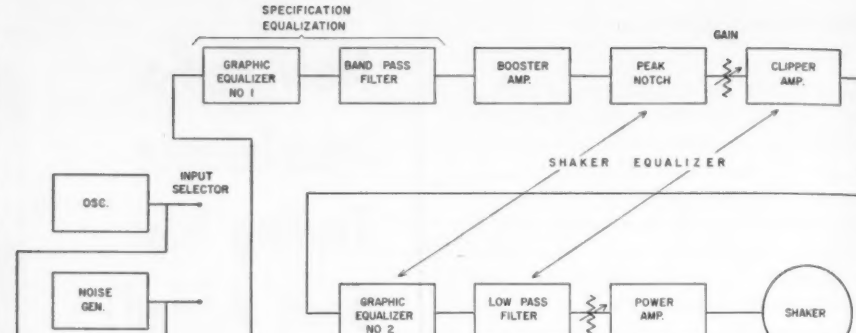

FIG. 3. Equipment required to duplicate dynamic environment is shown in this functional block diagram of a typical vibration testing system. System shown has sine wave, random wave, and customized complex wave testing capabilities. Magnetic tape can be used to provide signals with special amplitude-time characteristics.

the graphic equalizers has greatly improved control of spectrum shaping and reduced the time required in equalizing the system for testing. The equalizers provide amplitude control of the spectrum between 2 and 8000 cps. Each of the frequency selective attenuators of the equalizer controls the level of a small band of frequencies. Adjusting the positions of the attenuators produces a frequency response curve similar to the physical positions of the attenuators.

A booster amplifier placed after the specification equalization raises the level of the equalized signal to the level required for further shaping.

Once the output of the noise generator has been equalized to the test specifications, the characteristics of the electronic and mechanical portions of the test equipment must be compensated to produce the desired amplitude characteristics at the shaker table. This compensation not only cancels the effects of electronic resonances in the equipment, but also controls the effects of mechanical resonances and forces in the shaker and the very item under test.

To accomplish this system equalization a combination of graphic equalizers, low pass filters, band pass filters, and peak and notch filters are used. Figure 4 shows the steps in the equal-

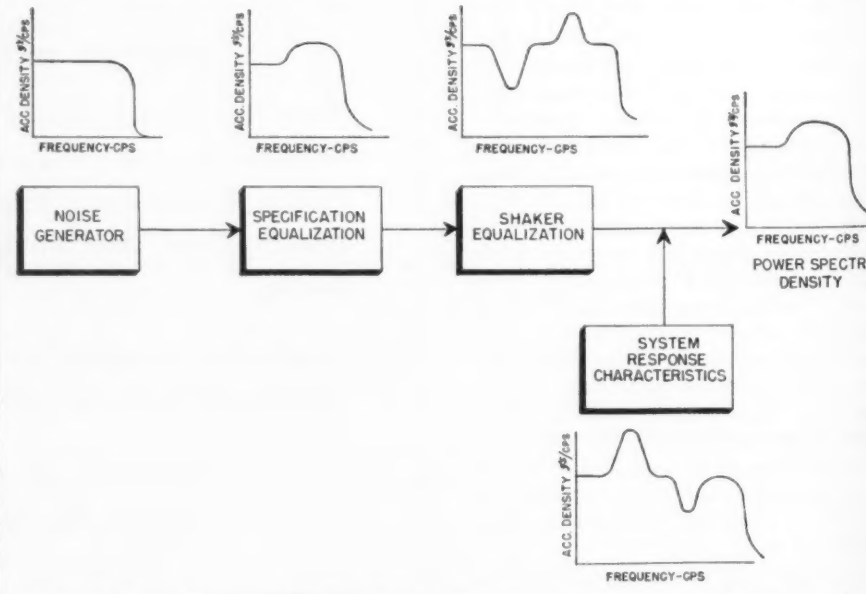

FIG. 4. Flow diagram of vibration testing system shows steps in shaping of required Power Spectral Density. White noise with finite bandwidth from noise generator is shaped to meet specifications. Shaker equalization counters response characteristics of electronic and mechanical elements of system. Resulting forces retain characteristics specified to duplicate vibration environment.

ization process from the output of the noise generator to the required Power Spectral Density characteristics at the shaker.

Of considerable interest are the peak and notch filters, Figure 5. These filters provide vibration test engineers with the capability of placing peaks and notches anywhere in the band spread of 2 to 5000 cps. These peaks and notches may be characterized by "Q" values of 0 to 1,000 and maintain adjustable heights and depths to 40 db independent of the "Q" value chosen.

In addition to compensating the driving signals for the characteristics of the system, the equalization equipment also serves as safety checks. The clipper amplifier placed after the gain control insures that no signals with amplitudes above a safe range for the shaker are transmitted to the power amplifier. The power amplifier is provided with an additional safeguard in the form of the armature protector which shorts the armature in the event of instantaneous overcurrent or overtravel.

Some idea of the power requirements necessary to duplicate the vibration environments to which today's missile systems are subjected can be had by considering that the power amplifier for vibration tests calls for 200 kilo volt amperes. Amplifiers of this size can provide peak shaker forces of 42,000 pounds at frequencies up to 2000 cps.

Up to this point in the vibration test system, the elements have all been electronic. The shaker itself is electrodynamic and presents the greatest portion of the system limitations. Electrodynamic shakers operate on the same principles as do radio loud speakers. Electronic signals applied to the armature set up magnetic fields about the armature coils which react with the magnetic fields about the field coils. The result is a force tending to move the armature. The armature is connected to the shaker table so that the force applied to the armature is transmitted directly to the shaker table.

The greatest limitation in shaker performance arises from its physical function—that is, the shaker must move a mass. The power required to provide this motion increases both with the mass and with the frequency of the signal. Nevertheless, even considering the disadvantages of electrodynamic shakers, they do provide the only successful means of transducing electronic signals into mechanical motion with any degree of fidelity and power.

Monitoring the motion of the shaker and the element under test calls for the use of specialized instrumentation able to faithfully report the test conditions while undergoing the vibrational loadings themselves. In general, rugged

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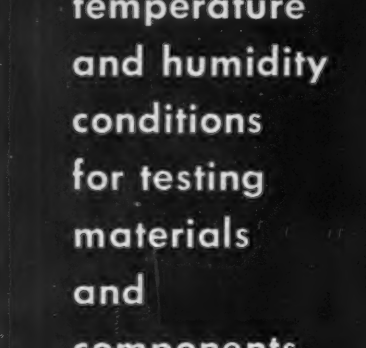

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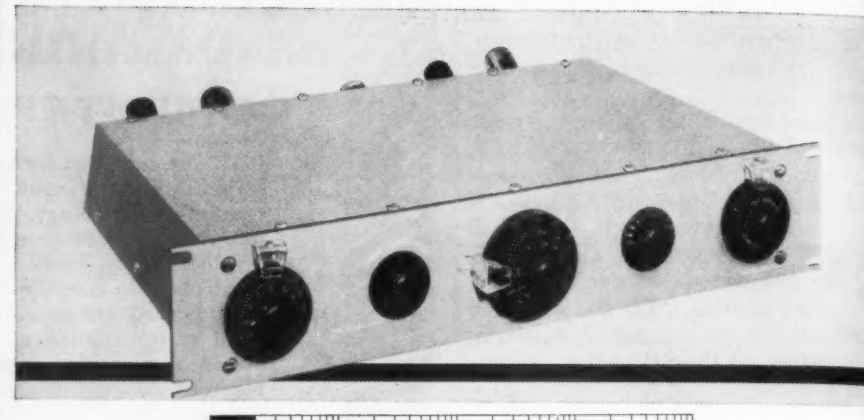


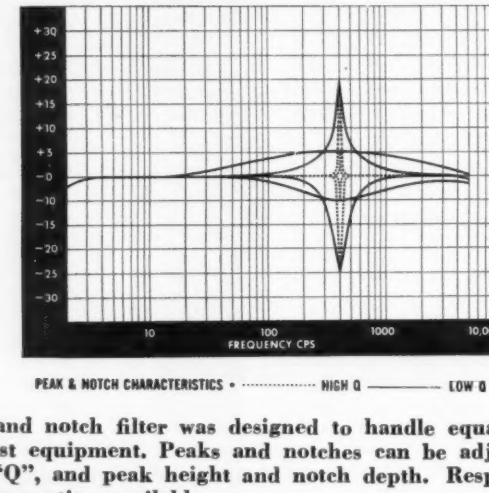


FIG. 5. Peak and notch filter was designed to handle equalization problems in vibration test equipment. Peaks and notches can be adjusted with regard to frequency, "Q", and peak height and notch depth. Response curve shows wide range of operation available.

accelerometers are used to monitor the vibration forces.

FUTURE EQUIPMENT

As environmental conditions become more severe and missile systems more complex, the trend in vibration testing is to more accurate reproduction of the conditions the missile and its components will encounter. This trend results from realization that the reaction of a large and complex missile system to vibrational forces can be considerably different from that of any one portion or component of the system. We need to increase capabilities of the vibration test equipment in both frequency range and force available at the output. Ideally, each missile system should be tested as a complete unit in a simulated environment duplicating not only the vibrational conditions, but also the temperature, pressure, and other conditions.

Foremost in the efforts to increase test equipment capabilities are developments toward more efficient and better performaning shakers. These developments are aimed at improving the operation of existing electrodynamic shakers at higher frequency and force conditions and under more strenuous pressure and temperature environments. At the same time development work is being directed at new concepts in shaker design and construction.

One new area of endeavor is the use of acoustical testing techniques. In these tests the missile and its components will be battered by sound waves generated by the equivalent of a huge loud speaker. Since sound wave transmission is rather inefficient, the missile will be placed in a resonant chamber to make use of the resulting reverberations to reinforce the generated waves. This area of testing is becoming increasingly important as the sound levels of rocket engines and aerodynamic turbulence increase to the point that they can physically damage missile structures and components.

Circle 94 on Inquiry Card

WORTH FILING

Antenna Systems Catalog

96-page product and facility book covers antennas, antenna systems, and transmission line products. Included are new product developments in 21-inch waveguide, high-power transmission lines, ground-to-air and telemetry antennas, microwave and two-way communication antennas, and the introduction of two new sizes of HELIAX (flexible coaxial line).

Source: Andrew Corp.
Chicago, Illinois

For your copy: Circle No. 227 on Inquiry Card

Structural Material for High Temperature Use

Reinforced ceramic material that resists gas erosion at extreme temperatures and eliminates structural failure due to heat shock can be fabricated for rocket nozzles, nozzle components, and other applications where materials must retain their shape and dimensions at very high temperatures. The normally brittle ceramic is quasi ductile. Negligible changes in rocket nozzle throats have resulted at temperatures of 5000 F for test durations of more than 60 seconds with actual rocket motors. Avco Research and Advanced Development Div., Wilmington, Mass.

Circle No. 165 on Inquiry Card

Dual-Rate Gyros

One rate gyro that will do the work of two units effects reductions in space required for instrument and control packages. In RG-18 series, one motor is used to drive two separate wheels, making it possible to measure rates about two different axes. For example, one unit can measure both pitch and yaw. Another gyro series, (RG-20) covers two rate ranges about the same axis. For example, a single unit covers the rate ranges from 0–20 degrees-second and from 0–200 degrees second, thus expanding the dynamic range of instrumentation system from 100 to 1 to 500 to 1 and giving greater accuracy. Built with two independent pickoffs (one for each axis or one for each range), these gyros, at temperatures from −65F to 180F can operate in relative humidity 100%, at unlimited altitude and excellent resistance to acceleration, vibration and shock. Humphrey, Inc., San Diego, Calif.

Circle No. 241 on Inquiry Card

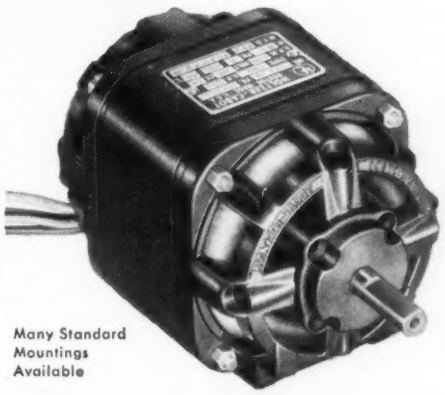
WORTH FILING

SR-4 Strain Gages

New catalog lists over 250 types of bonded filament resistance strain gages, and includes complete electrical and physical specifications of each gage type. Included are a wide variety of etched foil gages for high, intermediate and room temperature applications as well as all standard, semi-standard and special purpose SR-4 Wire Gages. A separate section provides data useful in the selection of gages for various applications. In addition, the publication lists strain gage instruments, strain gage kits and accessories.

Source: Baldwin-Lima-Hamilton Corp.
Electronics & Instrumentation Div.
Waltham, Mass.
For your copy: Circle 182 on Inquiry Card

New Designs in Motors from HOLTZER-CABOT



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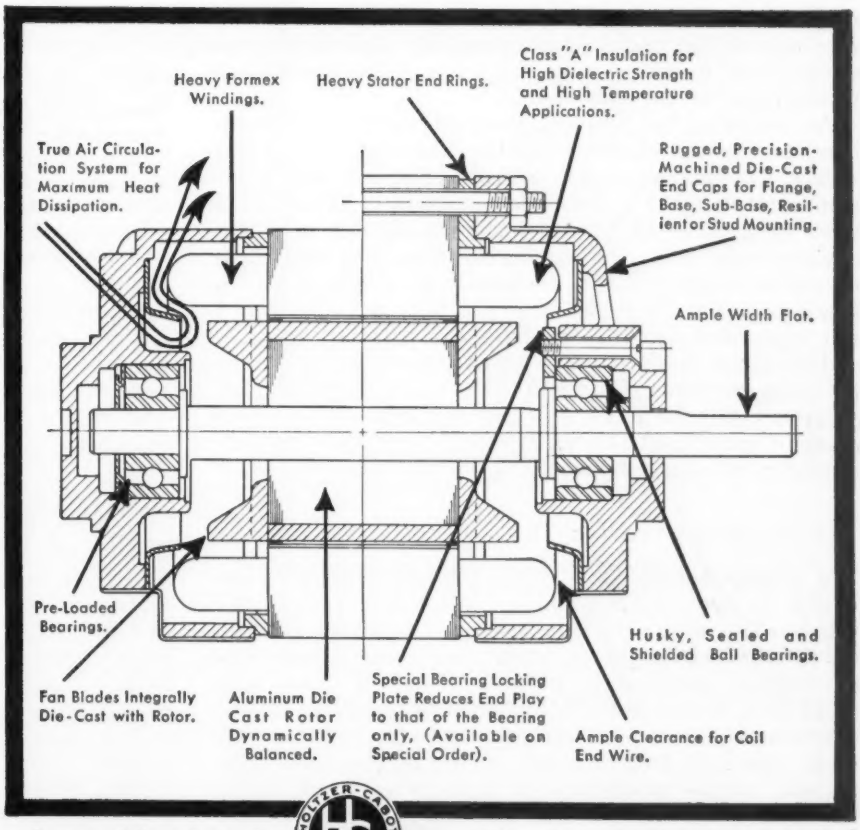
This motor is an ideal power source for recording instruments, timers, medical instruments, office equipment, blowers, tape recorders, communications equipment, etc. It is available in both 2-pole and 4-pole design, each in three stacking lengths. Type R-29 is a permanent split capacitor type available as an induction or synchronous motor. H.P. of various models ranges from 1/75 to 1/30. Construction features are indicated below.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CIRCLE 23 ON INQUIRY CARD

ENVIRONMENTAL TESTING OF BALLISTIC MISSILE RE-ENTRY VEHICLES

by C. A. Caputo, Reliability and Quality Department
Avco Research and Advanced Development Div., Wilmington, Mass.

The environments of flight and especially the re-entry of ballistic missiles have posed special environmental problems for Avco in its development of re-entry vehicles for the Air Force Titan and Minuteman intercontinental ballistic missiles.

Original estimates of environments to be simulated pointed out that some of the equipment needed simply did not exist. Temperatures, for example, were on the order of several thousand degrees Fahrenheit and rates of heat input, thousands of B. T. U.'s per square foot per second. Random and sinusoidal vibration to be expected were about 0.2 g^2/cps and plus and minus 5.0 "g" respectively, in the approximate frequency range of 10 to 2,000 cps, at least for brief periods during powered flight and re-entry. Maximum sound pressure level might be on the order of 155 decibels (re 0.002 dynes per square centimeter) with an approximate bandwidth of 20 to 4,000 cps. Acceleration, both sustained and oscillatory, might run as high as 100 "g" or more. Extreme low pressure outside the earth's atmosphere also had to be considered. And it was probable that some of these conditions would occur at the same time.

As a start on the problem, standard temperature chambers, temperature-humidity-altitude chambers, shock machines, shakers, centrifuges, altitude chambers, and other equipment designed to meet the conditions of MIL-E-5272 were used. Some of this equipment could not meet the environmental limits without improvement, and other conditions demanded the development of totally different, new equipment. To meet these conditions Avco developed test equipment like the arc-heated tunnel for materials and structural testing at very high temperatures, an acoustic noise generator, 100g and 200g shock machines, and a device called the TAVET (Temperature-Acceleration- Vibration-Environment-Tester) capable of simultaneously exposing parts and components to severe environments.

ACOUSTIC NOISE TESTING

The sound level of large rocket engines like those of an ICBM is approximately 155 decibels at the re-entry vehicle. The sound pressure level is transmitted through the surrounding air directly to the parts, even though they are isolated mechanically from structural vibration. This could be a serious problem for some components. To find out, it was necessary to design and build a device that could simulate such acoustic noise in the laboratory. Because of the availability of high-power amplifiers in the Avco environmental test laboratory (a part of the mechanical vibration systems), loudspeakers were used rather than sirens or modulated air flow horns. Since no speakers were available to produce the required acoustic power at frequencies below 500 cps (most of the energy in the rocket engine noise spectrum is concentrated between 50 and 500 cps), a 6 KW loudspeaker (figure 1), was designed and built. For testing small components (cross-sectional areas less than 20 square inches) the sound is directed into a progressive wave tube in which the component has been mounted (figure 2). For larger specimens, a pentagonal reverberant chamber was built.

With these facilities it was possible to determine whether

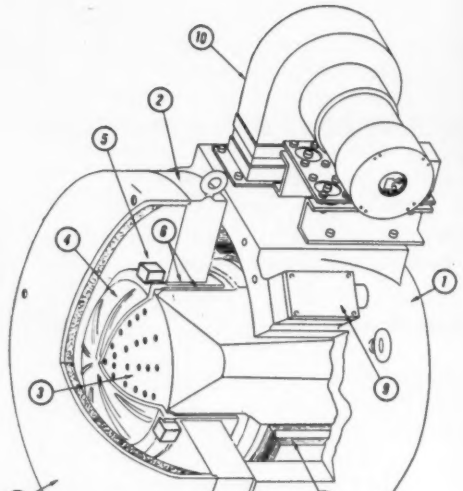

FIG. 1. The AVCO acoustic noise generator is a specially designed electro-mechanical transducer or loudspeaker of the moving coil type rated for continuous operation of sound pressure levels up to 166 decibels of random noise and up to 170 decibels at discrete frequencies. 1. housing 2. front plate 3. focusing device 4. moving coil 5. flexure system 6. annular gaps 7. field coil 8. shield 9. junction box 10. blower

the re-entry vehicle equipment could stand the acoustic environment associated with launching of an ICBM and the sound pressure levels of re-entry. In addition, attenuation characteristics of a complete re-entry vehicle were studied in a specially developed 900-cubic-foot reverberant chamber.

ELECTRIC ARC-HEATED WIND TUNNEL

The intense aerodynamic heating effect of high-velocity air on aircraft and missile structures is well known. It, of course, doesn't make any difference whether the air is flowing past a stationary structure, or the structure is passing through still air; the effect is still the same. This makes wind tunnels practical for aerodynamic experimentation.

Historically aerodynamic heating first came to the attention of the designer in the early 30's during the development of air-cooled radiators for high-speed aircraft. More recently the problem has come to the forefront with the advent of hypersonic re-entry vehicles for ICBMs.

Up to two years ago there were no test facilities available for continuously simulating the temperatures and heat transfer rates characteristic of re-entry. Continuous flow hypersonic tunnels were capable of producing Mach numbers up to 20, but at the expense of gas temperature in the test section. The test section temperatures were generally not sufficient to produce dissociation in the air approaching the specimen under study. The shock tube and hot-shot tunnel, while making it possible to reach a new regime in Mach number, pressures, and air temperatures, were hampered by their short (millisecond) characteristic

FIG. 2. Noise—100 million times greater than heavy five o'clock traffic noise is made by Avco's new acoustic noise generator. Designed to simulate the noise of a mighty rocket engine in the laboratory, the noise generator is helping to test critical components that will go into the Titan and Minuteman ICBM nose cones that Avco is developing for the Air Force.

operating times. Finally, the blast of a rocket motor was available for material studies. However, while this tool was able to continuously simulate the heat transfer rates and shear forces characteristic of re-entry, it had a limited temperature range, and the composition of the exhaust gases was very different from the composition of high-temperature air.

The electric arc-heated wind tunnel was developed as a result of the foregoing limitations. Unlike other laboratory tools for the simulation of re-entry, the electric arc gas heater is capable of continuously heating air to re-entry temperatures and pressures.

A schematic of the basic Avco air heater is shown in Fig. 4. The unit is a device for heating gases to high temperature by passing them through an electrical discharge. The fluid to be heated is injected tangentially into the chamber. The arc discharge is ignited by exploding a tungsten bridge wire which initially connects the carbon cathode and water-cooled copper anode. The injected fluid flows through the region occupied by the arc discharge, momentarily becomes part of the discharge, and is exhausted from the system.

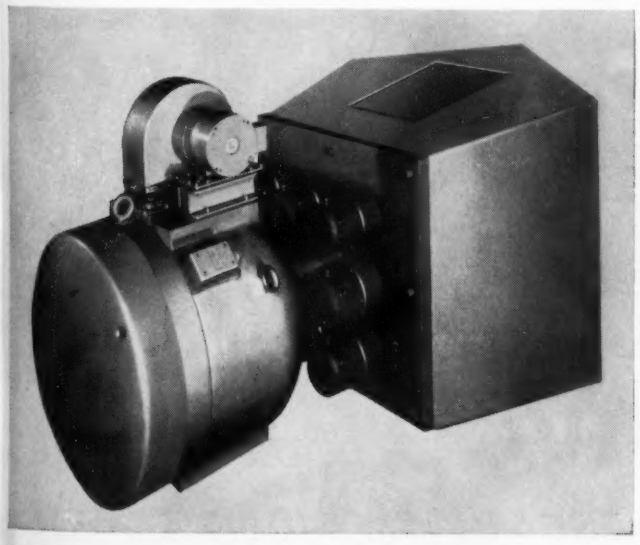

FIG. 3. Avco acoustic noise generator, shown with a reverberant chamber attached, allows laboratory acoustic noise testing of critical components and systems to military specifications. The high-intensity noise environment and frequency spectra generated are similar to those produced by rocket or jet engines.

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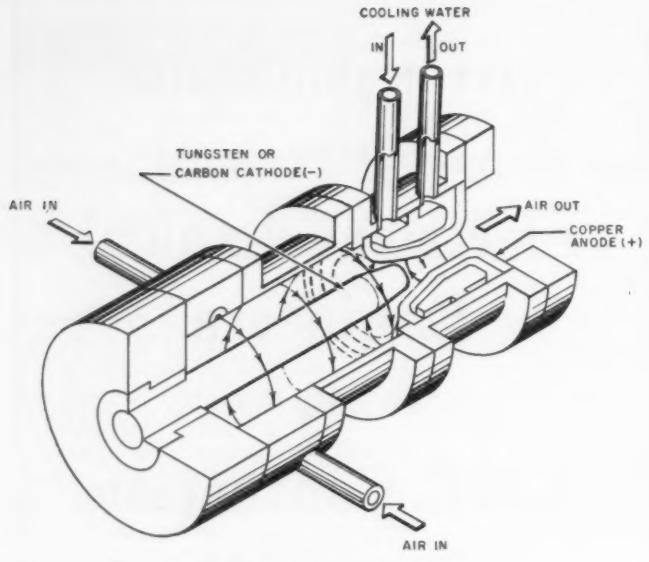

FIG. 4. Avco electric-arc air heater

The temperature of the exit jet can be varied from 3000 F to 12,000 F by changing the airflow. The unit has been operated both subsonically and supersonically by changing nozzle shape and discharge conditions.

Apart from problems of re-entry simulation the arc gas heater is an interesting low thrust, high-specific-impulse propulsion device. Preliminary measurements on a small thrust stand have indicated that the Model 500 arc heater operated with helium produces about 5 lbs of thrust at a specific impulse of about 500 seconds. Its possible use as a space propulsion device is being investigated by the Avco Research Laboratory in Everett, Mass.

TEMPERATURE-ACCELERATION-VIBRATION-ENVIRONMENT TESTER

The TAVET was built to study the simultaneous effect of temperature, acceleration, and vibration on re-entry vehicle parts. Two methods that readily suggested themselves for combining vibration and acceleration were:

(1) Mounting a vibration exciter at the end of a centrifuge arm.
(2) Shaking the hub of a centrifuge vertically with a vibration exciter.

Previous attempts to work out a design based on the first method were discarded as economically infeasible: exciters available commercially were large and cumbersome, and would require extensive redesign of flexures and other parts to withstand sustained accelerations of any magnitude. The advent of hydraulic exciter systems made the second method feasible.

To obtain the test facility as early as possible with a minimum of design effort, it was decided to adapt readily available commercial equipment. A centrifuge and a vibration exciter were combined and a brine chamber built around the outside of the centrifuge tub to provide the temperature capability (see figure 5). The test facility has been completed and is in process of evaluation. Tests indicate that sinusoidal vibration of up to 10 "g" on specimen weights of 20 pounds can be obtained over a frequency range of 30 to 400 cps. Higher frequencies are possible, but at levels below 10 "g". Frequency response curves at various points on the machine indicate a primary resonance near 70 cps and a secondary resonance

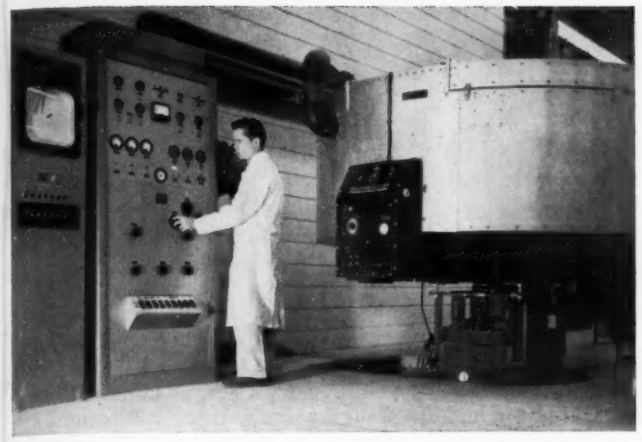

FIG. 5. Temperature, acceleration, vibration, environmental test chamber.

at 250 cps. Sustained acceleration can be obtained over an infinitely variable range of 1 to 75 "g". The brine conditioning unit is capable of maintaining any temperature from −65 F to 250 F in the test space. The machine's adaptability for use with random as well as sinusoidal inputs is under consideration, as well as the use of compensating networks to flatten its response to vibration.

One of the "by-products" of this machine is its ability to test inertial devices under vibration and at high and low temperatures. When used for such a device, the acceleration produced by the centrifuge is no longer merely an environment, it is an energy which the inertial device stores and uses to perform its task. From this point of view, the TAVET is a test facility in its own right.

Circle 96 in Inquiry Card

WORTH FILING

Application Notes For Magnetic Tape Recording

In addition to specification and performance characteristics for an entire line of tape recorders, this booklet contains notes on applying the equipment for wide frequency response, multiple channel recording, memory, time expansion and contraction, variable time delay and data reduction. Techniques are described for visual readout, digital presentation, electronic frequency analysis and programming of simulation devices.

Source: Leach Corp.
Compton, Cal,

For your copy: Circle No. 226 on Inquiry Card

Dynamic Measuring and Recording Instruments

16 page catalog covering dynamic testing by multi-channel oscillographs, recording oscillographs and accessories, data amplifiers and bridge balances, vibration measuring equipment and power supplies.

Source: Consolidated Electrodynamics Corp.
Pasadena, Cal.

For your copy: Circle No. 237 on Inquiry Card

Electronic Switching

Current issue of *General Telephone Technical Journal* starts a series of articles on electronic switching research. Series will cover transmission, memory and control circuitry.

Source: Automatic Electric Co.
Northlake, Illinois

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MORE leading companies work with more MB vibration test systems than any other. Avco too has added its distinguished name to the impressive list. In its modern facilities at Wilmington, Mass., Avco Research and Advanced Development Div., has a variety of complete MB systems; also a shaker-mounted centrifuge for combined acceleration, temperature and vibration cycling tests.

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KEARFOTT TACHOMETERS

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Kearfott offers one of the broadest lines of precision tachometers in the industry. Light, compact and resistant to temperature, vibration and shock, they are available for a wide variety of applications.

Size 11 (R860)

Integrating Tachometers, special types of rate generators, are almost invariably provided integrally coupled to a motor. They feature tachometer generators of high output-to-null ratio and are temperature stabilized or compensated for highest accuracy integration, rate computation, etc. In addition to reducing the in-phase null level toward zero, errors due to temperature effects are minimized over a wide ambient range. Linearity, in some cases as low as .01%, is usually better than ±.1%, while phase shift is 0±1°. For extreme accuracy, models with low temperature coefficient drag cups are also available.

Rate Generators feature high output-to-null ratios and are designed for application as rate servos and to provide damping in very high gain systems. These Kearfott units offer high linearity, high output and low inertia and are often integrally coupled to a low inertia motor; in this design the in-phase null is virtually reduced to zero. Quadrature null is as low as .25% of the 1000 rpm outputs while harmonics seldom exceed .1% of the output at 1000 rpm.

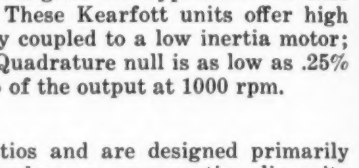
Damping Tachometers have relatively low output-to-null ratios and are designed primarily for damping purposes. They feature extremely low inertia and power consumption, linearity which is normally within ±.5%, and phase shift within 10° of reference. Kearfott damping tachometers are usually integrally coupled to a low inertia motor.

INTEGRATOR TACHOMETERS

(Typical Characteristics)

	Size 11 (R860)	Size 15 (T816)	Size 18 (V892)
Excitation Voltage (400 cps)	115	115	115
Volts at 0 rpm (RMS)	.020	.020	.010
Volts at 1000 rpm (RMS)	2.75	2.7	2.00
Phase shift at 3600 rpm	0°	0°	0°
Linearity at 0-3600 rpm	.07	.05	.07
Operating Temperature Range	−54° + 125°	−54° + 125°	−54° + 125°

TEMPERATURE

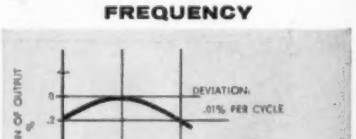


RATE TACHOMETERS | DAMPING TACHOMETERS

(Typical Characteristics)

	Size 15 (R800)	Size 18 (V806)	Size 8 (M824)	Size 10 (P822)	Size 11 (R809)
Excitation Voltage (400 cps)	115	115	26	115	115
Volts at 0 rpm (RMS)	.013	.026	.015	.019	.019
Volts at 1000 rpm (RMS)	3.1	3.0	.234	.450	.5
Phase shift at 3600 rpm	5°	4.5°	10°	5°	5°
Linearity at 0-3600 rpm	.25	.25	.3	.3	.3
Operating Temperature Range	−54° + 100°	−54° + 125°	−54° + 125°	−54° + 125°	−54° + 125°

FREQUENCY



INTEGRAL SERVO MOTOR DATA

(Typical Characteristics)

	Size 8	Size 10	Size 11	Size 15	Size 18
No Load Speed (RPM)	5400	6600	5500	8000	8000
Stall Torque (oz. in.)	.3	.35	.55	.45	1.30
Excitation Voltage (400 cps)	18-40	26-40/20	115-40/20	115-40/20	115-115/57.5
Rotor Moment of Inertia (Gm.CM²)	1.3	.76	7.7	7.0	35
Operating Temperature Range	−54° + 100°	−54° + 125°	−54° + 125°	−54° + 125°	−54° + 125°
Unit Weight (incl. tachometer)—oz.	3.1	4.6	9.0	14.0	30

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CIRCLE 26 ON INQUIRY CARD

Part 1 of Components Digest 3 appeared in the February 1959 issue.
Part 3 is scheduled May 1959.

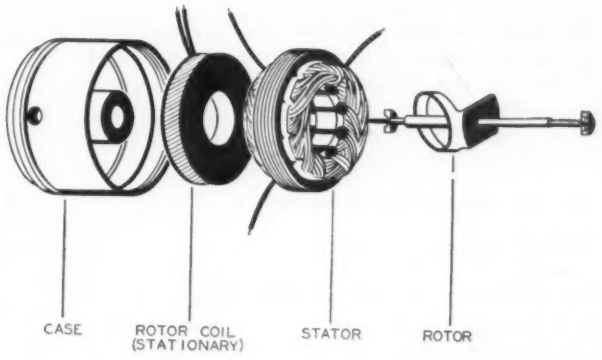


Fig 11.1—Exploded view of a Synchrotel

Synchrotels

The Synchrotel, developed by Kollsman Instrument Corp., functions either as a very low-torque control transformer or inductive pick-off. The movable element of the unit can be coupled directly to sensitive aircraft instruments to convert, with a high degree of accuracy, the instrument movement into electrical signals. The Synchrotel may be coupled to low-torque shafts, such as a gyro-gimbal shaft whose angular position is to be transmitted.

An exploded view of a Synchrotel is shown in Fig. 11.1. A single-phase winding, corresponding to the rotor winding of a conventional synchro, is wound on a spool surrounding the lower section of the cylindrical core which runs up the center of the case. The case is made of a highly-permeable magnetic material. The stator is a conventional polyphase synchro-type assembly located in the case above the rotor winding (which is stationary), and also surrounding the cylindrical core. The rotor consists of an oblique section of a hollow cylinder attached at one end to the rotor shaft. The oblique section rotates in the annual clearance between the core and the stator teeth, and the shaft passes through the center of the hollow core. The rotor made of aluminum has minimal weight. The shaft terminates in instrument pivots which run in sapphire bearings. Since there are no brushes, and there's no electrical reaction at the null, positioning torque need be only sufficient to overcome the friction of the jewel bearings.

In operation, either as a control transformer or as an inductive pick-off, the stator windings are excited with alternating voltages which produce a resultant radial-alternating flux. (See Fig. 11.2). Any of this flux that links the single-turn loop of the rotor induces a current in the loop, in turn, producing an axial component of alternating flux in the cylindrical core. This flux induces in the rotor winding an alternating voltage whose amplitude is a sinusoidal function of the relative positions of the rotor and of the stator radial flux.

High angular resolution and accuracy with minimum required positioning torque of the prime mover are obtained by several factors:

- Rotor weight and moment of inertia are held to an absolute minimum.
- Absence of brushes and the fact that the rotor pivots turn in sapphire bearings make static friction torque negligible when the unit is energized.
- Rotor is effectively skewed with respect to the pole pieces. This minimizes pole-piece effect on accuracy and assures no change in accuracy due to axial play.
- All iron-to-iron air gaps are in stationary members, and are therefore relatively insensitive to any radial play in rotor bearings.
- Reaction torque at null voltage position is always zero. With a condenser of proper value across the output winding, there is no perceptible electrical reaction for any rotor position.

Since tooth errors are substantially eliminated by the design of the rotor, the principal error as a function of angular position is in the form of a smooth sine-wave in one cycle for 360 degrees rotation of the rotor.

OPERATION AS A CONTROL TRANSFORMER SYNCHRO

The Synchrotel is most frequently used in a servo system similar to that shown schematically in Fig. 11.3. A sensitive mechanism receiving pressure information (pressure, altitude, air speed, etc.) transforms this information into rotation of the Synchrotel rotor. The rotor will then rotate as a function of input pressure. The signal generator synchro rotor is connected to an a-c supply, and, according to its position, induces different voltages in the three Y-connected stator windings. These voltages are fed to the Synchrotel stator, where a resultant field is established whose position is determined by the rotor position of the generator synchro. Then the voltage in the rotor winding of the Synchrotel is a sinusoidal function of the difference between the agular positions of the Synchrotel rotor and the signal generator rotor. The rotor voltage is amplified to actuate the control phase of a two-phase servo motor which drives the signal generator to one of the two positions which produce a null in the Synchrotel rotor. In doing so, the rotor of the signal generator synchro is continually following the rotor position of the Synchrotel. The signal generator rotor, therefore, rotates as the same

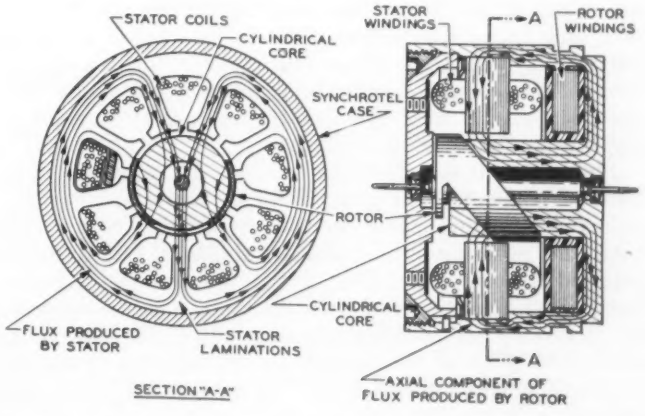
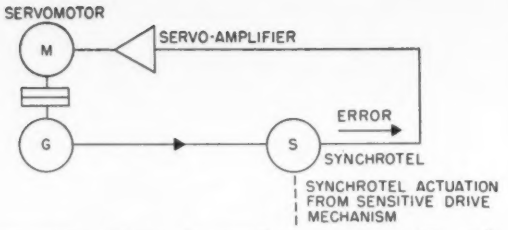


Fig 11.2—Sectional views of a Synchrotel showing its flux pattern.

function of the input pressure as that of the Synchrotel rotor. Selection of the desired null position is accomplished by properly adjusting the relative phasing of the signal generator rotor and the motor fixed phase, and the amplifier phase-shift characteristics.

OPERATION AS AN INDUCTIVE PICK-OFF

Where it is desired to obtain an ac phase reversal of 180 degrees for an extremely small angular motion, a substantial volts-per degree gradient with a very low minimum can be obtained from a Synchrotel. To secure an in-phase signal, a condenser is usually connected across the Synchrotel rotor leads. Value of the condenser depends on impedance of the load fed by the Synchrotel. The rotor has 360 degrees rotation with no ambiguous points at any position. Therefore, since the output signal is continuous, the pick-off can not "get lost". The output voltage amplitude is proportional to the sine of the angle away from the null. By using the Synchrotel as an inductive pick-off in a follow-up system, a working accuracy of several hundredths of a degree may be obtained.



The servomotor drives the synchro generator, G, rather than the synchrotel, as is customary.

Fig 11.3—Inverted servo loop employing Synchrotel as low-torque transmitting device. In contrast to conventional arrangements, the synchro generator is driven by the servo motor.

APPLICATIONS

The Synchrotel is adaptable to flight and engine instruments. It may be incorporated within the case diameter of a regular dial-and-pointer instrument, or in a blind transmitting instrument to be remotely located. The Synchrotel may be used to transmit angular position of any low-torque shaft. It is particularly useful where very high accelerations and/or rapid oscillations are to be measured.

Angular accuracy is not effected by temperatures of −55C to +70C. These accuracies remain the same as at room temperature.

Accuracy	**5 Seconds of arc**
Repeatability	**1 Second of arc**
Sensitivity	**.25 Second of arc**

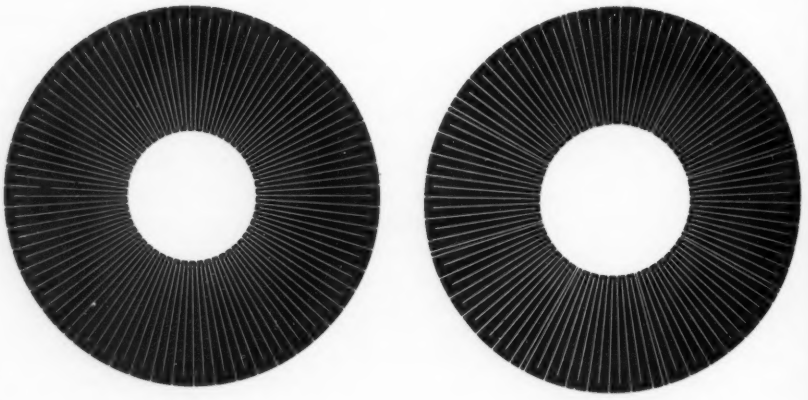


Fig 12.2—Elements of the Rotary Inductosyn

Inductosyns

Where precise positioning accuracies greater than those obtainable even with multi-speed transmission systems are required, the Inductosyn may be considered. The rotary and linear motion varieties of this device have accuracies of 5 seconds of arc, or ±0.0001 inches respectively. This compares with best accuracy of about ±½ minute available in a two-speed synchro system employing the best possible gearing.

Physically, the Inductosyn consists of engraved patterns of conductors on glass plates to form a multi-polar inductive structure. Only a structure of this type could have the necessary dimensional stability to achieve the required accuracy. Because of the absence of magnetic material, carrier frequencies of the order of 10 kilocycles are necessary for efficient coupling. Similarly, the large number of poles of the Inductosyn require use of a conventional synchro system as a "coarse control" to avoid ambiguities in positioning.

As an electrical data transmission device, the rotary Inductosyn is similar to an electrical resolver having a single input winding and a pair of uncoupled output windings. However, in the Inductosyn there are a large number of poles, and a complete voltage cycle is produced for a rotation equal to the spacing between pole pairs. Rotary Inductosyns are normally built with 108, 128 and 144 poles, corresponding to 54-speed, 64-speed and 72-speed resolvers. That is, an Inductosyn transmitter behaves like a single-input high-precision resolver having a large number of poles or else is geared up in the above ratios. Some of the most useful arrangements of both rotary and linear Inductosyns exploit this electrical identity by using Inductosyns and resolvers in combination to permit novel applications.

If two rotary Inductosyns are paired and their stationary (stator) coils coupled together, they may be used as transmitter and receiver for transmission of angular data in much the same way as a pair of resolvers might be used. However, because of the large number of poles, a succession of ambiguous null points appears, equal to the number of pairs of poles less one.

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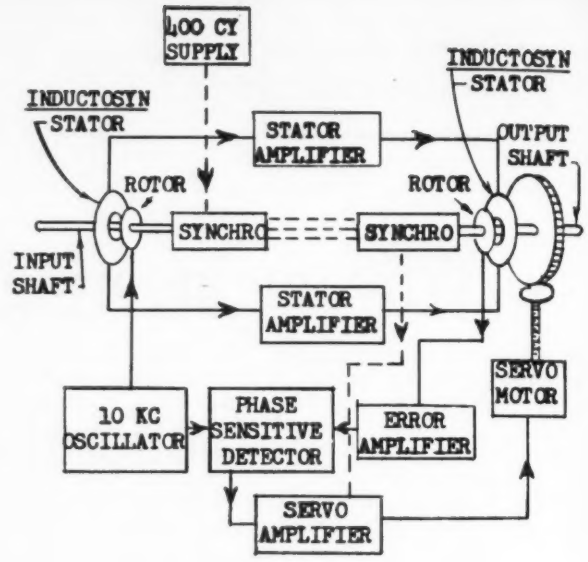


Fig 12.1—Inductosyn servo system

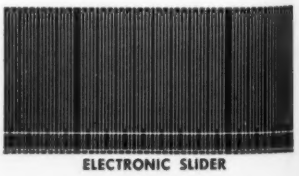
Fig. 12.1 shows an Inductosyn transmission system in simplified form. Figs. 12.2 and 12.3 show the structure of the inductive components of the rotary and linear Inductosyns respectively, with brief descriptions of the mode of operation. The error curves are approximately sinusoidal in shape, with a half-amplitude of about 5 seconds of arc. Repeatability of data is of the order of one second of arc, or 25 micro-inches.

APPLICATIONS

The rotary Inductosyn provides a means for precise measurement of angular position, for data pick-off from gyroscopes and other sensitive elements, for precision servo systems, for missile guidance, fire control and other military applications, as well as for other measurement and control applications. The linear Inductosyn provides a means for accurate control of machine elements moving in translation and for precision measurement of length. A most significant use is in automatic machine-tool control systems.

Because of its unique character, the Inductosyn may be used in a variety of unusual applications where it would be extraordinarily difficult to apply conventional components. Table 12.1 lists a number of these applications and show the circuitry necessary for some. Naturally, applying a component with the accuracy of the Inductosyn requires a series of precautions as well as special techniques to insure proper installation and operation, which can best be determined by consultation with the manufacturer.

Accuracy	.0001 of an inch
Repeatability	25 micro inches
Sensitivity	10 micro inches


ELECTRONIC SLIDER

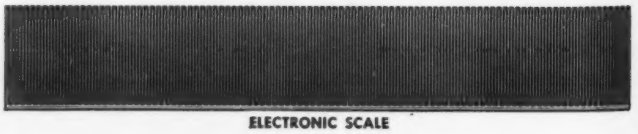
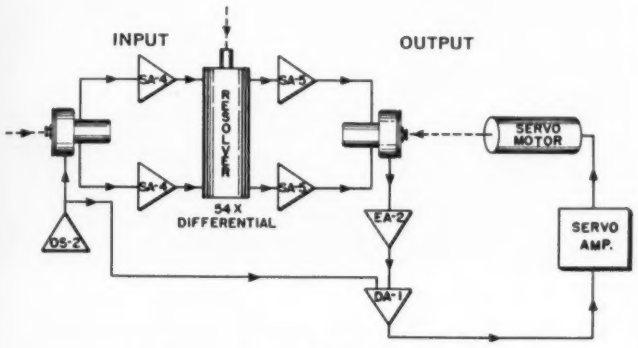

ELECTRONIC SCALE

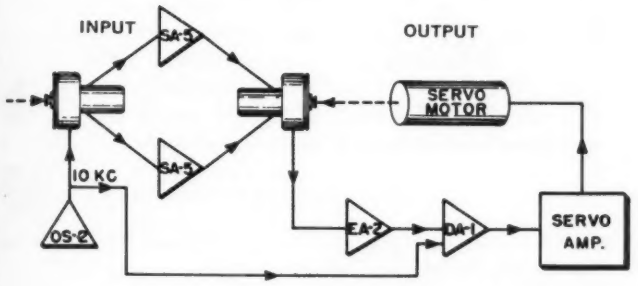
Fig 12.3—Elements of the Linear Inductosyn

Table 12.1

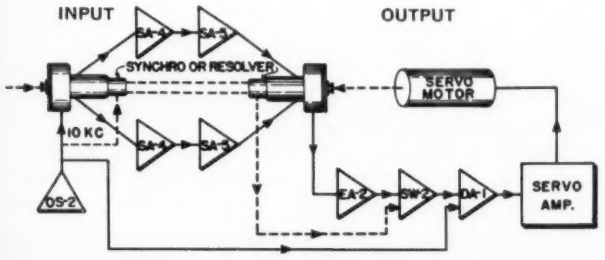
APPLICATION CIRCUITRY FOR THE INDUCTOSYN



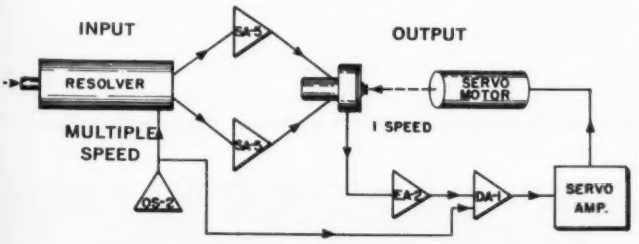
Inductosyn in a Differential System



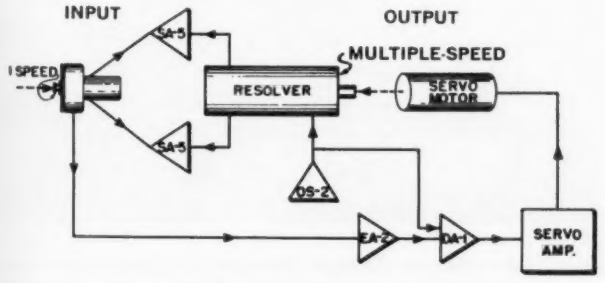
Repeater System on a One Speed Shaft



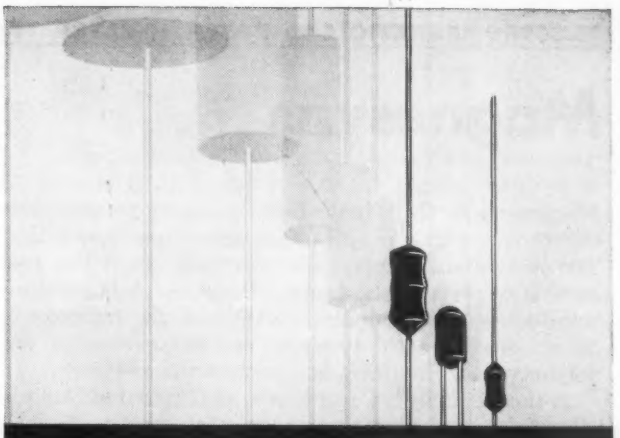
Repeater System with Synchro for One Speed Operation



Inductosyn as a Gear Ratio (Step-Down)



Inductosyn as a Gear Ratio (Step-Up)



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Magnesyns

Magnesyns in their basic form are a-c operated, rotating electro-magnetic components for remote position indication. Transmitter and receiver are identical units. The rotor of each is a permanent magnet. Rotation of the transmitter rotor causes corresponding rotation of the indicator rotor. Magnesyns are used to drive pointers or similar devices not for power transmission.

In the Magnesyn, a soft-iron toroidally wound ring is put around a magnet so that most of the magnetic lines of force pass through the ring, as shown in Fig. 13.1. Electric current applied to the toroidal winding, generates additional magnetic lines through the ring. If the current is large enough, the iron ring is saturated during peak portions of each current cycle. Thus, the magnetic lines from the permanent magnet in the center decrease during those portions of the cycle. During the alternating current cycle, because there are two peaks, the flux lines from the permanent magnet reduce to a minimum twice per cycle. As a result, the permanent magnet behaves very much like double frequency alternating magnetomotive force. This double frequency is generated in the winding of the toroidally wound soft iron ring. Dividing the electrical winding into three sections causes the voltage induced in each section by the pulsing lines of force from the magnet to vary with the position of the magnet. If the magnet is rotated, the voltage in each section will change accordingly.

Two identical Magnesyns, energized from the 400 cycle or 60 cycle line, with their tapped points inter-connected, function very much like a conventional synchro system having analogously a double frequency applied to each of these rotors. There is, in effect, a torque transmission system and each Magnesyn tends to follow the other. This is the basic principle of operation of a Magnesyn system.

A Magnesyn can also be devised in which straight line motion of the magnet occurs. Instead of placing the ring around the rotating magnet, you place a soft iron tube or cylinder around a magnet so that the magnet is free to slide back and forth within the tube. Most of the magnetic lines of force pass through the walls of the soft iron hollow tube. An electrical winding is provided around the outside of this soft iron tube. With this construction of magnetic parts and electrical winding the relationship of lines of force from the magnet and lines of force from the alternating current in the winding is exactly the same as for the rotary type of Magnesyn. Since, as in the rotary Magnesyn, the winding is divided into three sections, a straight line Magnesyn can be connected directly to a rotary Magnesyn. In this fashion straight line motion at a transmitter can be reproduced as a rotary motion at an indicator without resorting to mechanical linkages of any kind.

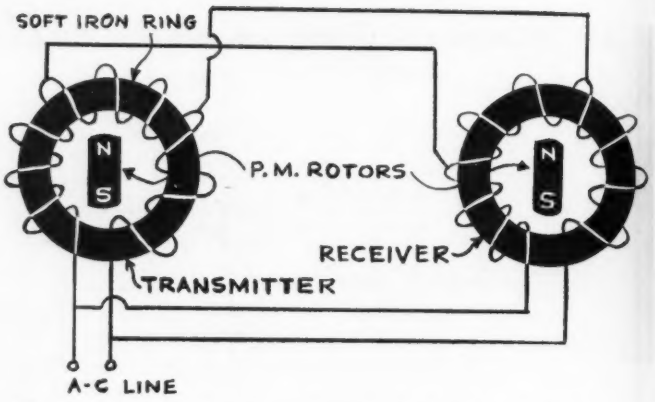


Fig 13.1—Basic Magnesyn Remote Indication Circuit

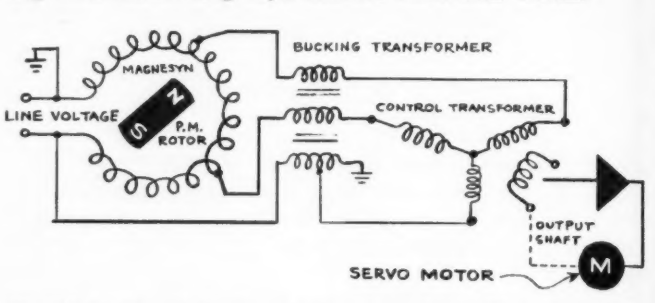


Fig 13.2—Use of Magnesyn in a servo-loop. The servo must operate on double the line frequency.

The Magnesyn can also be used in conjunction with a conventional control transformer and servomechanism in a synchro system. Here, the fundamental component of Magnesyn output as applied from the line is cancelled out by bucking transformers so that only the induced second harmonic resulting from the permanent magnet flux pulsation remains. The second harmonic is applied to the control transformer lining so that the control transformer cannot drive a servomechanism to a null at a double frequency carrier. This arrangement is shown in Fig. 13.2.

Microsyns

The term Microsyn refers to the four pole structure of Table 14.1. This device, developed at M. I. T. during World War II, has served a large variety of measurement and control applications requiring accuracy and sensitivity over a limited angular range. They have been particularly suitable as components of gyro systems, but recently they have found application in many types of industrial as well as military devices.

Physically, the Microsyn consists of a four pole stator and especially shaped rotor, both of laminated high permeability magnetic steel. It is analogous to a circular differential transformer, or to a variable-reluctance balanced-bridge signal generator of the type described previously as an E-type pick-off. As a result of the balanced bridge construction, the microsyn compensates for errors that might

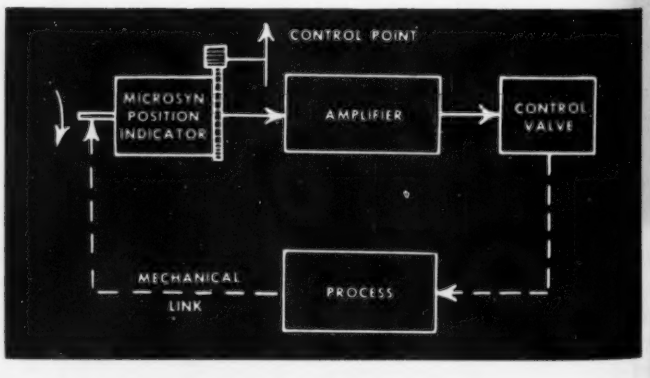


Fig 14.1—*Process Control.* Due to its low torque requirements, the Microsyn may be used to great advantage in process control where the primary sensing element develops a very small driving force.

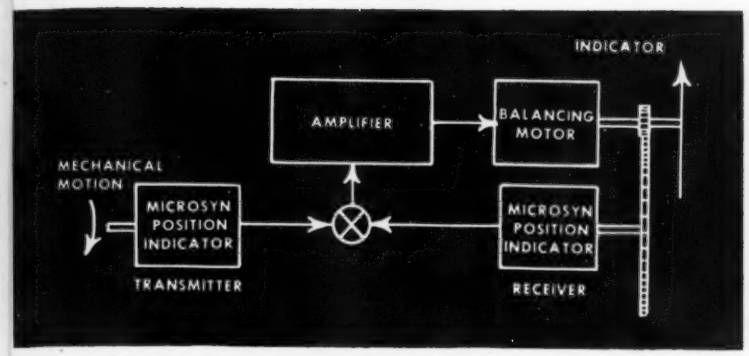


Fig 14.2—*Data Transmission.* In linear balancing systems of the telemetering type, the microsyn is ideal for such applications as the measurement of pressure, temperature, or flow. The low voltage electrical line is trouble free and safe and can be conveniently connected to a remote indicating point. System accuracy is subject only to the limitations of the primary sensing element. In its simplest application and where compactness and light weight are important, the Microsyn output may be fed directly to an indicator.

otherwise be introduced by mechanical symmetry.
Important features of the Microsyn are:

- High linearity, including phase reversal at null, over a limited angular range.
- Resolution of the order of 0.01 degree, concurrent with very high signal to noise ratios.
- Low operating torque or friction as a result of absence of slip rings or other mechanical restraints, and the balanced low inertia rotor. Undesirable electro-magnetic reaction torques are negligible.
- High sensitivity with high volts output per degree and other scale factors associated with the various applications of the Microsyn.
- Good reliability as result of simplicity of mechanical construction. In many applications the Microsyn stator and rotor elements are coupled directly to the application parts whose relative motion is being measured. The basic Microsyn units can be reconnected in a variety of ways to serve a number of special purpose functions described below.

The Three Basic Microsyn Functions

The three basic Microsyn types are described and illustrated in Table 14.1; signal generator, torque generator, and elastic restraint generator. In each instance, the configuration of Microsyn coils that provide the required function is indicated, together with a brief description as to just how the function is obtained. The table similarly includes the basic performance characteristic corresponding to the function in question as well as several performance curves showing errors in achievement of the function.

Common Applications

The most common Microsyn application is as a position indicator or a signal generator. In this application it can be used in conjunction with Bourdon tubes, bellows, various flow meters and manometers, etc. to measure pressure. It can be used in conjunction with bimetallic elements and other temperature sensitive devices to measure temperature. Linear and angular dimensions, density, humidity, viscosity, and other quantities can be measured and converted to an electrical signal by the signal generator. Figs. 14.1 through 14.4 illustrate applications of the Microsyn to various industrial and military problems as suggested by Boston Division, Minneapolis Honeywell.

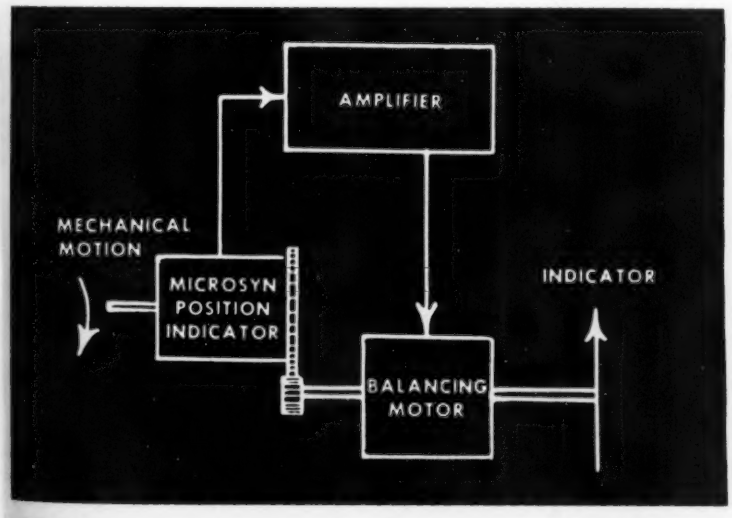


Fig 14.3—*Measurement of Mechanical Variables.* The Microsyn is incorporated in a self-balancing servo system providing torque and motion amplification. Such an arrangement finds application, for example, in viscosity determinations, micrometry, and for barometric pressure indication. Similar systems also find common military usage in gyro instruments for angular displacement and rate measurement, as well as in acceleration measuring equipment.

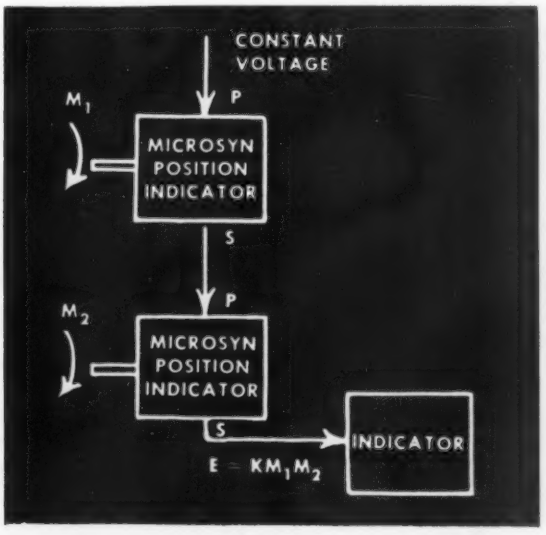
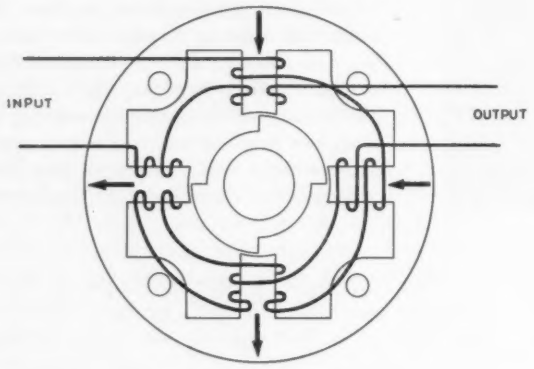


Fig 14.4—*Computing.* Microsyns, by virtue of their high sensitivity and low reaction torque, may be used for addition, subtraction, multiplication or division of variable mechanical inputs. A method for obtaining the product of two variables is illustrated.

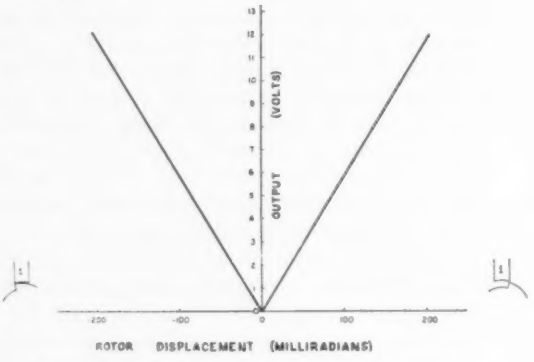
Table 14.1 – MICROSYN TY

SIGNAL GENERATOR

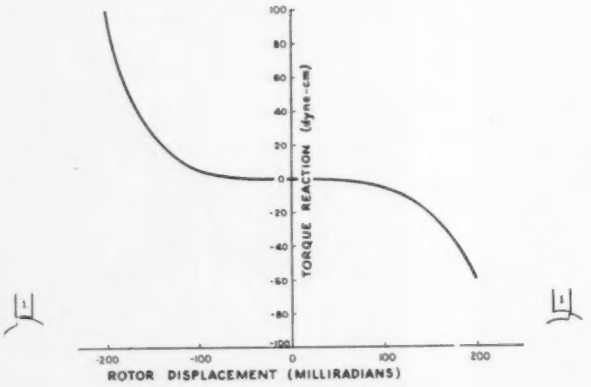


DESCRIPTION

Generates output voltage proportional to displacement angle, over limited angular range. Negligible magnetic reaction torques. Excellent sensitivity and linearity, and low null voltage. Operates only on alternating current. Pick-off in very low torque systems.



Signal generator performance: in phase signal output

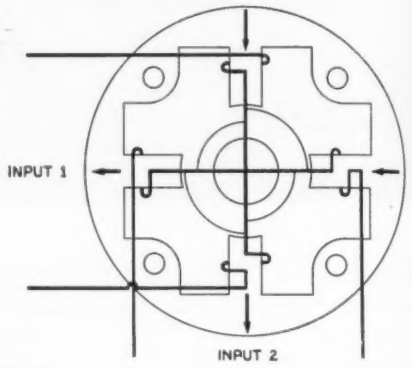


Signal generator performance: torque reaction

THEORY

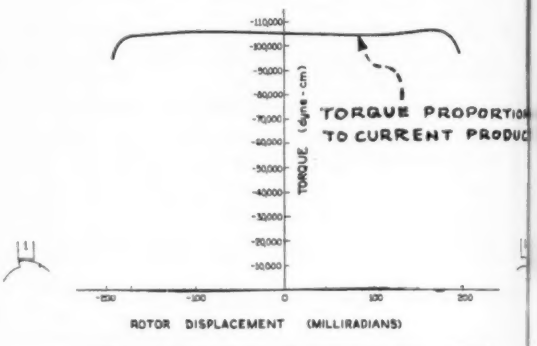
The *signal generator* primary in the null position, as a result of its symmetry, has no net output coupling with the output winding. However, should the rotor be turned from null, fluxes in the two opposing legs increase while fluxes in the remaining legs decrease, resulting in an unbalance, with a net voltage induced in the output winding. Under ideal conditions, the increase and decrease in flux of the pole groups cancel so that primary inductance is maintained constant. Therefore, there is no reaction torque.

TORQUE GENERATOR

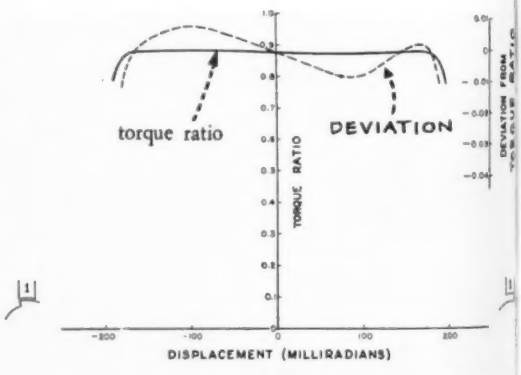


DESCRIPTION

Develops output torque proportional to product of two in currents. Torque is independent of angular position over s operating range. Excellent linearity and sensitivity; operates d-c and a-c. Torque unit in gyro system or force-balance se



Torque generator performance: torque output

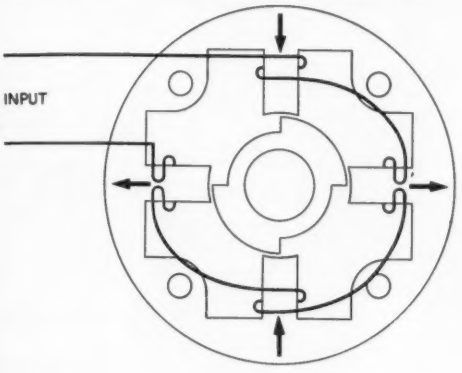


Torque generator performance: torque output ratio

THEORY

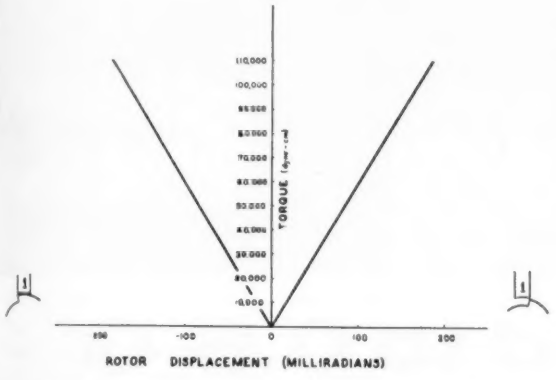
The *torque generator* has basically the same winding arran ment as the signal generator. For a linear signal genera the variation in mutual inductance between primary and s ondary is a linear function of angle. Since self-inductance primary and secondary are constant according to the reason applied to the signal generator, then reaction torque, veloped is proportional to the product of the currents of i and output windings and the constant rate of change in mu inductance with respect to angle. Thus, the torque gener develops a torque proportional to the product of its curr and at the same time the torque is relatively independen angular position over the range.

ELASTIC RESTRAINT GENERATOR

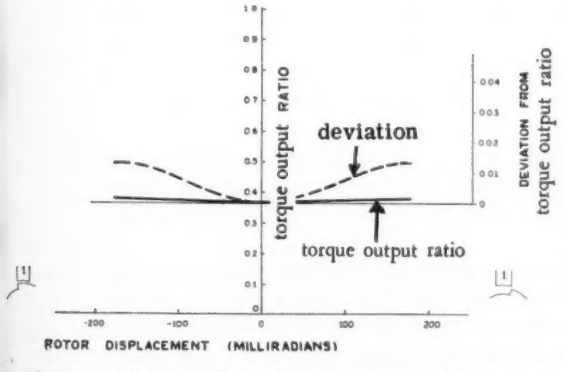


DESCRIPTION

Develops a spring-type restoring torque which varies as the square of the applied current. Moderate accuracy. Relatively large leakage fluxes. Used as an "electrical spring".



Elastic restraint generator performance: torque output



Elastic restraint generator performance: torque output ratio

THEORY

The arrangement of coils in the *elastic restraint generator* is such as to give a linear variation of self-inductance. Departures from ideal performance are more pronounced in the elastic restraint generator than in other applications. This unit is little used, since its function may usually be achieved with a torsion spring.

A wide selection of the new Bristol stock 7/8" OD capsular elements is now available in pressure ranges from 15 to 350 psi.

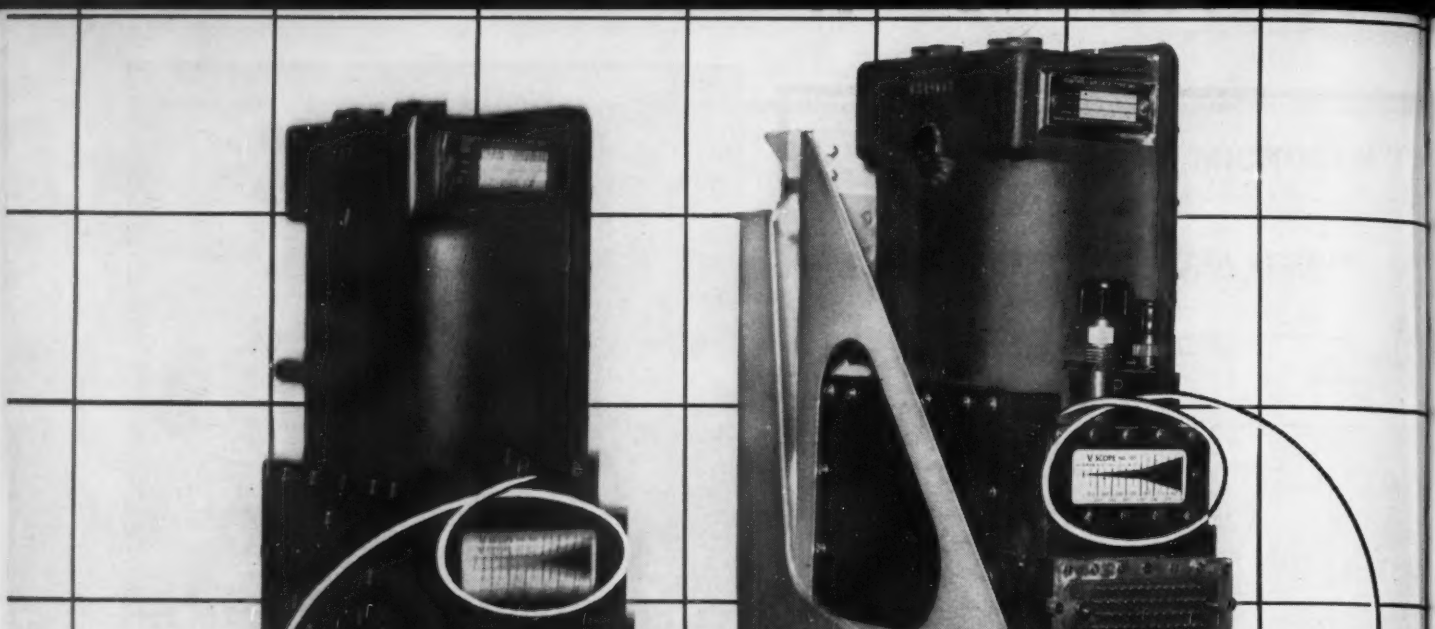
These are the latest of Bristol's long-life, Ni Span C pressure sensing elements widely used in the aircraft and instrument fields. For applications requiring miniaturization, this new 7/8" OD is the optimum size. Nominal deviations from linearity of these precision miniatures is less than 1%.

Other Bristol stock capsular elements range from 1 3/32" to 2 11/32" OD and have a nominal deviation from linearity of less than ½% (deviation due to hysteresis of less than ¼%). Normal operating temperature range is —65° to 300° F. . . . for higher temperatures to (550°) a slight 2% travel change may be expected.

Bristol has been manufacturing pressure sensing elements for 70 years. For further information on these capsular elements with outstanding linearity characteristics write for Bulletin AV2001: Aircraft Components Division, The Bristol Company, Bristol Road, Waterbury 20, Conn. 8.54

BRISTOL FINE PRECISION INSTRUMENTS FOR SEVENTY YEARS

CIRCLE 32 ON INQUIRY CARD



The Vscope on the front of each equipment is shown here enlarged to improve readability. The Vscope at left shows a vertical disturbance of .187". The Vscope at right reveals no apparent motion due to the high isolation of the Robinson mounting.

12.0 "G" reduced to 0.6 "G"

This Is Environmental Protection!

Look at the above illustration, showing two Bendix air data sensors on an electromagnetic shake table. Notice the left hand unit which is mounted solidly to the oscillating head of the shaker. The image is blurred because a vibratory input of about .187" double amplitude at 35 c.p.s., equalling an acceleration force of 12 "g's", is being applied directly to it.

Now look at the right hand unit mounted on a Robinson engineered mounting system . . . some difference! The clear image of this equipment shows the typically high isolation efficiency (over 95%) of the Robinson MET-L-FLEX® mounting design.

Other Robinson designs provide similar protection at higher frequencies where the input often reaches 30-40 "g's". The natural frequencies of such mounting systems are held within limits which are not critical to the equipment.

Utilizing this mounting system radically reduces the environment to a level easily tolerated by any reasonably well designed electronic equipment. Such a mounting eliminates the need for costly and time consuming ruggedization. Over-all space and weight are held to a minimum.

Because of the proven performance and reliability record of airborne components *now* protected by Robinson mountings, an increasing number of manufacturers in the electronics industry are incorporating Robinson mountings as an *integral part* of their basic equipment design.

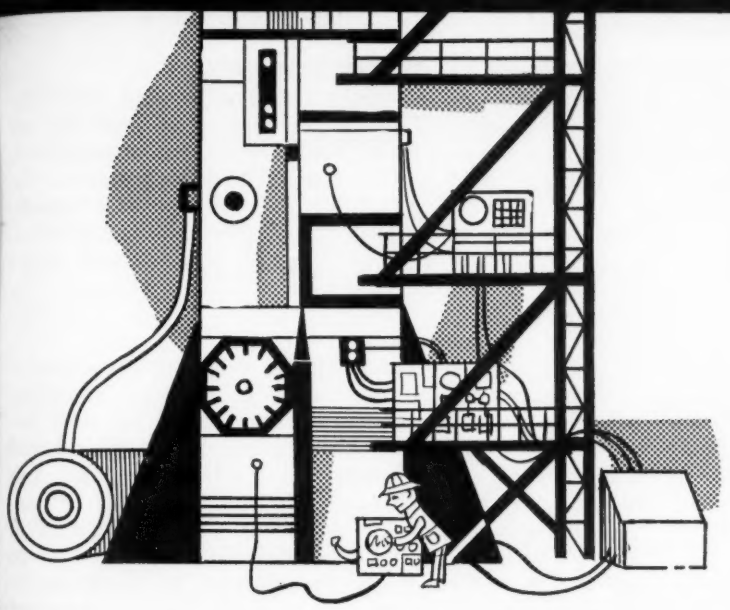
"Performance is the reason . . . Reliability the Result"

ROBINSON CONTROL IS RELIABILITY CONTROL

ROBINSON AVIATION INC.
TETERBORO · NEW JERSEY

West Coast Engineering Office: Santa Monica, Calif.

DESIGNERS AND MANUFACTURERS OF VIBRATION CONTROL SYSTEM



COMPONENTS 4 DIGEST

A Second Part of CD-4 is scheduled for June 1959

ENVIRONMENTAL TESTING Part I

The problem of environmental testing is how to assure the reliability of equipment containing many diverse parts, under increasingly severe environmental conditions. In this Components Digest, we consider aspects of the problem that concern individual components and sub-system packages. A detailed coverage from this point of view provides background for future Components Digests, and will avoid the problem of repetition in treating environmental characteristics of individual components in this monthly series.

The object of environmental testing is then to anticipate failures that might occur in use in sufficient time to provide design corrections. Because actual environmental conditions are a complex combination of inter-acting effects, laboratory testing can at best merely provide an approximation to the real conditions. Increasingly severe environments, and unanticipated failures make it necessary to continually analyze the bases of environmental testing to achieve more accurate correspondence to actual conditions. The great variety of conditions under which a particular piece of equipment may operate greatly complicates the problem. Also, certain "natural combinations" of environments tend to be far more severe than the environments of individual tests, making selection of natural combinations from the vast body of possible combinations extremely difficult. New requirements are adding new environments particularly as a result of advances in space flight and atomic energy.

Experience is a big factor. Familiarity with the components under test, the nature of individual environmental tests, and the general causes of failure, and an accumulation of test reports from the laboratory and field, as well as a good basic engineering background, particularly in chemistry, materials and finishes, and structural design, are important. In particular, evaluation of a brand new component may require utmost engineering investigation to determine important weak points, since there is no previous history to suggest where to begin.

In the early stages of a design, environmental tests may be conducted on a quite informal basis. The engineer may merely leave a couple of suspicious components in a salt spray chamber while someone else's test is going on to see where failures may start. This type test at the very beginning, carried on frequently as components, materials and finishes are selected, is the best possible way to be assured of an adequate product later in the program. Even components known to be inadequate for the application, may, in the absence of better components, be subjected to these tests to focus attention on possible failure points of the finally designed component. It is almost axiomatic that no amount of paper analysis, or care in design, can anticipate the many possible points of failure, which makes the habit of early testing a vital one.

These informal environmental tests need not be carried out to any particular specifications. Many engineers may try to guess the most likely points of failure as a basis for their environmental testing. Overly severe environments may be applied to accelerate failures, permitting immediate corrective action, but results of such tests must be very carefully interpreted. Failures under excessively severe conditions, particularly temperature, vibration and shock, can be very misleading. Some companies, in their search for the ultimate in reliability, apply an alternating sequence of increasingly severe environments, and correct failures as they occur until satisfaction is achieved. This type testing can be very fast and economical.

Long term life tests should be undertaken as soon as possible. Some tests, such as five-year shelf life, for example, cannot be carried out during the course of the development program because of a great amount of elapsed time required. To meet such problems, the engineering department should accumulate records, reports and test data on a continuing basis, so that adequate back-ground information is available to deal with these problems as they arise.

Qualification Testing

In contrast with environmental testing, which is an engineering design tool, qualification testing is more formal, usually conducted on a contractural basis as part of the requirements of a job. These tests are conducted under certified conditions with formal reports verifying the compliance of the equipment with the performance and environmental requirements of the purchase order. A properly designed piece of equipment, whose components have been through appropriate environmental testing, undergoes qualification testing in a most routine manner, with faults if any, confined to a minor easily correctible nature. Aside from the relatively high cost of qualification testing, major failures at this point are particularly expensive to correct design wise. Likewise, delays in shipping may hold up major military programs. The importance of successfully meeting qualification requirements should be impressed on design personnel from the very start of the project.

←CIRCLE 33 ON INQUIRY CARD

COMPONENTS DIGEST

Reliability

Reliability is less concerned with design details than it is with the overall probability of failure. It is more of a mathematical study, the major problem being to secure an accurate mathematical model of the reliability factors in a piece of equipment. Where large numbers of components are concerned, the reliability requirements for individual components to achieve a good overall reliability are vastly tighter than normally expected.

Definitions of failure and life constitute an important aspect of any reliability program. In many missile applications, the required operating life is trivial in comparison with test time and storage requirements. Failure is often defined in terms of the permissible degradation of performance that will not impair the successful functioning of the overall equipment. The problem of reducing the complex real situation to a sufficiently accurate mathematical model is most difficult.

The field of reliability analysis is very broad, and problems must be judged individually. Future requirements dictate more and more emphasis in these areas, with perhaps a weakening of the cry for miniaturization. New space age programs are forcing a strong re-evaluation of the philosophy of environmental testing and its extension to reliability problems.

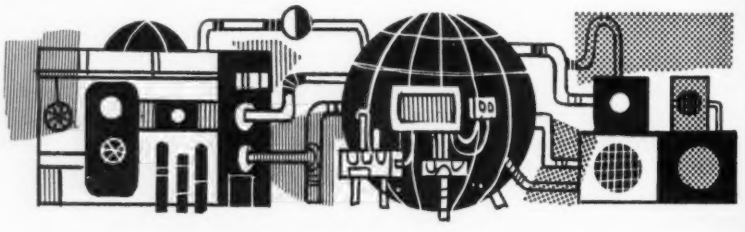
The importance of mathematical aspects of reliability has been heightened by a recent trend to spell out reliability as a portion of the procurement specification, with responsibility on the manufacturer to guarantee the required reliability. Reliability, however, is an extremely expensive item to guarantee. An adequate demonstration of reliability requires a great many samples tested under a variety of realistic environments. The problem is far too complex to even define adequately. Current reliability investigations are strongly centered in this area.

In the case of certain classes of ground equipment used under reasonably uniform conditions, a simplified reliability study may be based upon the mean time between failures in the intermediate use period after initial difficulties with the equipment have been corrected and before wear has started to sharply increase the failure rate.

In the case of missiles and telemetered data, the final test of reliability is in field service reports. But since actual tests to measure missile reliability are economically impossible, reliability must be mathematically determined on the basis of data of a more elementary nature. For example, the reliability of individual soft-solder joints may be determined by field reports, at least very approximately. Such data, together with information on how many similar joints are in a given piece of equipment, may permit a reasonable estimate as to the likelihood of failure from this area.

In certain classes of equipment reliability may be more accurately represented by a percentage of down time. An easily serviced unit may be permitted more failures than one less easily serviced. Thus emphasis on ease of servicing, plug-in replacement components, adequately trained personnel, and good instruction manual, is part of the whole reliability picture.

Environmental Test Laboratories



The increasing importance of environmental testing in achieving reliability has resulted in formation of a large number of environmental test laboratories. For flexibility in scheduling closer control of tests, particularly of large systems, because of the highly specialized nature of certain requirements, and perhaps to save money, larger systems companies have their own laboratories. Frequently they have test equipment whose rating or capacity could be achieved only by custom design. Specialized high-cost items are sometimes justifiable only on the basis of a large contract indicating definite need for the equipment. Such facilities, when properly approved by government inspectors, are permitted to issue certified test reports for approval or qualification purposes. Often such companies find it profitable to enter the commercial field and carry out tests for outside organizations for a fee. To carry out this activity successfully, the finances should be set up so that the test laboratory does not carry an excessive engineering overhead from the companies' other operations.

Strictly commercial laboratories have sprung up in all key industrial areas of the country. These laboratories are, roughly speaking, competitive in price and quality of performance, and selection is generally made on a regional basis for more effective coordination. Occasionally, however, some specialized piece of equipment (a random noise shake table, for example) may be available in relatively few locations.

Environmental test laboratories keep complete files of important sepcifications, and it is usually enough to specify the title, number, issuing organization, date and pertinent paragraphs defining the required test. However, tests that determine performance suitability and failure must be spelled out explicity; test laboratories are very experienced at adhering to the letter of your instructions and cannot guess the "obvious" points in your mind. Where tests require special equipment to determine suitability of performance, arrangement must be made to loan the equipment or purchase it. Often technical personnel of the engineering organization will carry out electrical tests, or at least participate, under the overall supervision of the environmental test technician responsible for certification.

Costs of environmentally testing a component are based upon the nature and variety of tests required. Standard price lists are generally available covering not only costs for use of test equipment but also rates for technical personnel involved. These price lists plus a detailed facility brochure often are sufficient choice factors in selecting a test laboratory. In many instances, particularly for vibration testing, the cost of special fixtures and test devices must be added to the basic costs.

It takes a TEAM
to solve timing problems

The control of time is an extremely complex science that demands a thorough knowledge of many individual technologies. For this reason, Haydon maintains a team of engineering specialists to provide the reservoir of skill, knowledge, experience, and creative ability necessary to solve industry's timing problems.

When you submit a timing problem to Haydon, it's handled by a team of specialists – *not* an individual engineer. And you can be sure the Haydon Timing Team is equipped with all the electric, electronic, mechanical and manufacturing know-how needed to analyze your requirements and develop the best possible new or modified timing unit for your specific application.

Correctly designed and efficiently manufactured, Haydon timing devices are exhaustively tested before release to a customer. The results are uniformly high quality devices that are known for fine performance, and long life. May we put our Timing Team to work for you?

A few units from the complete Haydon line are shown at the right. Send now for further information, outlining your requirements.

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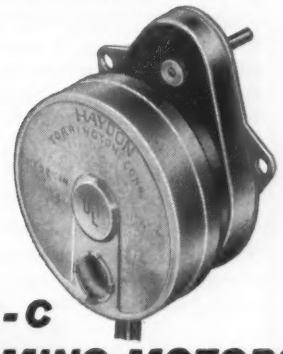
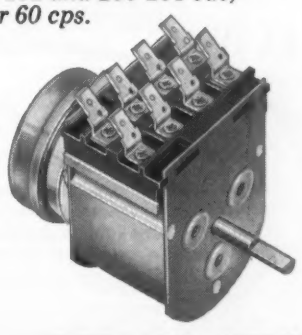
ELAPSED TIME INDICATOR ED-71

Compact, low-cost instrument for machine tools, communications equipment and other commercial applications where an accurate record of operating time is desired. Time Registered: 9,999.9 hours. Weight: 5 oz. Voltages: 120 or 240 v, 60 cps. Power Required: 2.5 watts at 120 v, 60 cps.



A-C TIMING MOTORS

A complete line of synchronous, compact timing motors, speeds from 1/60 to 60 rpm. Guaranteed torques from 6 ounce-inches to 30 ounce-inches at 1 rpm. Voltage ranges 103-132 and 206-264 vac, 50 or 60 cps.



INTERVAL TIMER

Directly controls heavy duty electrical loads. Type AD can be supplied with up to 3 SPST switches. Type AT has 1 SPST switch only. Intervals available with dial and knob: 15, 60 and 180 minutes. Intervals to meet your specific requirements can be supplied. Voltages: 120 or 240 v, 50 and 60 cps. Switch Rating: 28 amps, 250 vac non-inductive; 1 hp, 240 vac.

CIRCLE 34 ON INQUIRY CARD

FOR ENGINEERED SOLUTIONS TO SHOCK AND VIBRATION PROBLEMS

The parallel plane isolation mount pictured above, (in this instance, used as a Gyro mount) is just one example of the many special engineered systems developed by Federal for critical applications.

As specialists in all phases of shock and vibration control, Federal welcomes complex problems like these. Federal's diversified experience in building tens of thousands of mounting systems for airborne and ground-support applications is available to you for development of vibration and shock control systems to your specific requirements.

When "off-the-shelf" mounts won't do, it will pay you to talk to Federal. A letter outlining your requirements will place our engineering staff at your disposal.

For free data file on Federal engineered mounting systems write today to Dept. EMD

See us at I.R.E. Show Booth No. 3814

FEDERAL SHOCK MOUNT CORP.
Division of THE KORFUND CO., INC.
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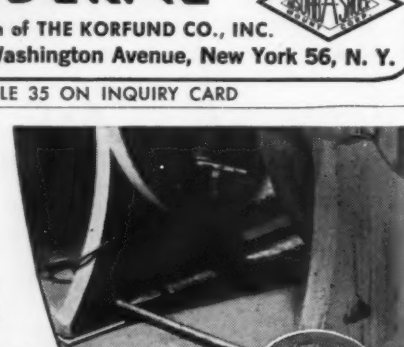
CIRCLE 35 ON INQUIRY CARD

Check Harmful Vibration At Its Source



UNISORB
MACHINE MOUNTS

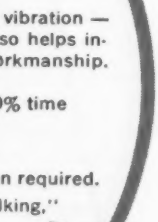
Unisorb reduces up to 85% of transmitted vibration — protects against unseen wear and tear. Also helps increase machine speeds, get better quality workmanship.

PLUS . . . these money-saving extras:

- Up to 30% cheaper installation costs, 80% time saving.
- No floor drilling, no bolts or lag screws.
- Firm anchoring, yet permits moving when required.

Permanent alignment, no machine "walking," precision shimming.

FREE Sample and Booklet . . .
Tells how and why Unisorb will pay off for you. Mount just one of your machines and feel the difference. Send reader service card, call or write . . .



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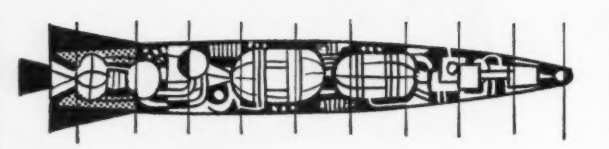


Military Specifications

As part of the approach to environmental testing, government agencies have issued standard general specifications. These specifications are prepared after study has revealed the applicability of such standards to a range of applications. However, the time lag between current developments, and standardization processes, often results in the rapid obsolescence of the latter. Systems specifications explicitly prepared for specific projects often have far more stringent requirements than specifications for the incorporated components. Thus many components currently being manufactured to standard military specifications are entirely unsuited to severe system requirements. As a result manufacturers frequently prepare their own component specifications tied to system environmental requirements. These special specifications are frequently modeled after standard military specifications with suitable exceptions, usually with extended ranges of environment.

As a result of increasingly severe environmental conditions, particularly in the areas of vibration and high temperature, component manufacturers are constantly being urged to develop "specials". Because of the narrowness of the application, or long and uncertain delays prior to production, as well as shortage of specialized component design engineers, manufacturers find that development of "blue sky" specials is generally unprofitable. In many areas almost no government money is available to support such development, leaving systems engineers with a long term, increasingly difficult procurement problem.

Notwithstanding the differences in specifications prepared to suit particular project requirements, the standard environmental specifications are still very important. They are under constant review with occasional major revisions to keep them up to date. Additional specifications relative to special components or to nonmilitary environments (such as the recent SAE specifications on servmometers and synchros) are closely related to the standard military specifications. The systems man, and the project engineer, as well as the component designer should be quite familiar with these standard specifications, their meaning and format, the significance of the tests described, the type of apparatus used, and the nature of the failures that may be precipitated by each of these tests. The component design engineer in particular must visualize the effect of the individual environmental tests on the item he is designing. The systems man must examine his packages with vibration and shock, cooling and other environmental requirements always in mind. A good familiarity with the standard military specifications provides an excellent basis for preparing or calculating new more severe specifications aimed at specific project requirements.

A great deal of aircraft electronic equipment is designed to meet the requirements of MIL-E-5400. This specification covers design and manufacturing requirements for piloted aircraft electronic equipment. It must be supplemented by a "detail" performance and test specification related to the particular equipment.

ANA Bulletin #400J, "Electronic Equipment: Aircraft, Applicable Documents", lists the latest applicable specifications, standards, drawings, and publications to be used in the design and construction of airborne electronic equipment. Use of this list of specifications is indicated by MIL-E-5400. It includes all the major components and processes apt to be incorporated in an electronic equip-

ment. It also includes a QPL (Qualified Products List) of government approved components. MIL-T-5422 supplements MIL-E-5400, covering specifically environmental testing under simulated and accelerated environments.

The most complete general purpose coverage is provided by MIL-E-5272A, specific paragraphs, or slight modifications, being widely quoted or referenced in the detail specifications of electronic components. A tentative revision of this is MIL-E-005272B, still awaiting approval. Alternate procedures of varying severity are listed for many of the tests to permit selection by the design engineer. MIL-STD-202 is a similar general environmental test specification that applies particularly to electric and electronic circuit elements.

These four military specifications, MIL-E-5400B, MIL-E-5272B, MIL-T5422C, and MIL-STD-202 are very widely encountered. The principal tests called for by these specifications are summarized in Table I.

To point up the nature of the tests, and possible points of failure, Table II has been prepared, roughly based upon the more important tests of MIL-E-5272A.

Random Vibration Testing

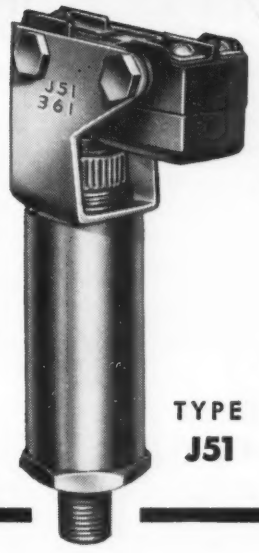
To aid in the more accurate simulation of environment, and therefore advance the cause of reliability through environmental testing, random and complex-wave vibration testing has been introduced. While sine-wave vibration testing is still widely used, random vibration requirements are being added to specifications for aircraft and missile equipment. Random vibration often consitutes a severe environment for reliable airborne electronic equipment.

Random vibration simulates the actual vibration encountered in various locations of rockets and missiles. Appropriate intensities and power spectra distribution must be established by estimates based upon field measurements. Presence of a band of frequencies in place of the discrete frequencies of sinusoidal testing can excite simultaneous resonance modes, or resonances within a minute portion of the structure too small to be observed during sinusoidal testing but important in terms of the life of some small portions of the assembly. The slider on a potentiometer or a relay contact, for example, may incur a complex resonance under random vibration testing. Often, a combination of a sinusoidal and random vibration are specified. Devices have been developed for simultaneous vibration and acceleration testing. Temperature and vibration tests are often combined.

Principal components of a random vibration test system are illustrated in Table III. Design of such equipment is highly specialized, and the underlying concept is fairly new. Ling Electronics, Inc. of Los Angeles, Cal., and MB Manufacturing Co. of New Haven, Conn., have complete lines of electronically driven vibration systems. High power random vibration systems frequently include limiters as safety devices to prevent overdriving the output coil of the shaker during the occasional peaks inherent in any random vibration pattern. Limit stops to disconnect the coil are also incorporated as a safety precaution. Some problems that occur in random vibration test equipment are:

- Frequency limits of transducers for measuring or recording random vibration.
- Equalization of sharp high frequency resonances introduced by the shaker.
- Resonances due to the load, both linear and nonlinear. The method of load fastening is particularly important. For testing large structures, either a series resistor (for low power systems) between the power amplifier and the shaker coil, or current feedback, where more power is handled, provide more accurate input signal transmission.

Wide Range Space Saving **J51**



PRESSURE VACUUM CONTROL

TYPE J51

United Electric's Type J51 Pressure-Vacuum Control is a skeleton, precision-built unit that is used extensively in applications where space and weight are factors. It has an uncalibrated adjustment that may be provided with locking feature if desired. It is a rugged, wide range control suitable for a multitude of uses.

Adjustable Ranges . . .	Models available in ranges of 50, 75, and 250 psi between 0 and 350 psi limits.
Switch Differential . . .	Approximately 5 or 10 psi dependent on model.
Switch Ratings	Up to 15 amps. at 115 or 230 volts A.C. Also available are 20 amps. A.C., manual reset, D.C., and other switches.
Switch Types	Normally Open, Normally Closed, or Double Throw — no neutral position.
Maximum Pressure . . .	350 psi.
Electrical Connections . .	Lead wires attached to screw type terminals on switch.
Pressure Connection . .	Via a ⅛" male NPT connection.
Mounting	Via pressure connection.
Bellows Material	Either type 321 or 347 stainless steel.

UNITED ELECTRIC ***manufactures a complete line of temperature, pressure, and vacuum controls. For applications requiring custom-built units or modified standard units, call upon a UE application engineer for recommendations. Complete data is available for the Type J51 as well as for all standard UE controls.***

UE® United Electric Controls COMPANY
85 SCHOOL STREET, WATERTOWN, MASS

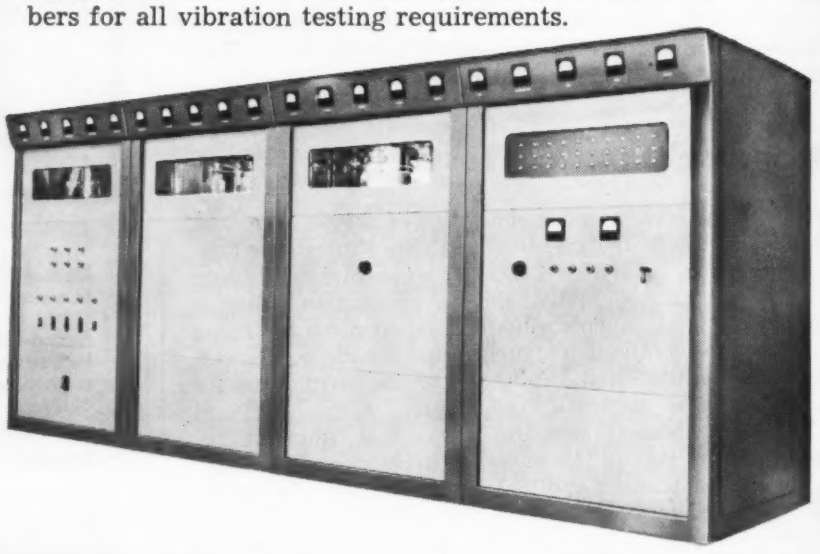
CIRCLE 37 ON INQUIRY CARD

LING *a complete line of random, complex*

Ling Electronics is today the nation's largest manufacturer of complete vibration test systems for random, complex and sine wave testing. These matched systems include high power electronic amplifiers, programming and control equipment, and electrodynamic shakers or acoustic chambers for all vibration testing requirements.

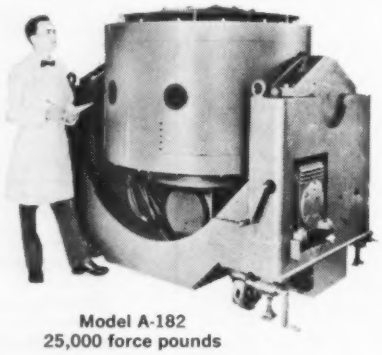
POWER GENERATORS

Ling Electronic Power Generators provide full system performance over the entire frequency range. They feature integrated field and degaussing supplies to suit any shaker requirement, and can be operated remotely from master control consoles or at the generators themselves. They are available in power ratings, from 250 VA to 175,000 VA.

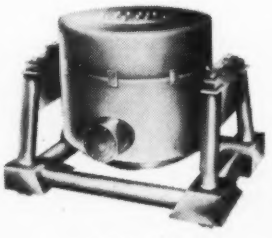


SHAKERS

Ling now engineers and manufactures a complete line of advanced electrodynamic shakers in all output ratings, from 25 to 25,000 force pounds, in both air and liquid cooled models. Ling liquid-cooled shakers are designed to be used with environmental chambers operating over a wide range of temperature, humidity and altitude conditions.



Model A-182
25,000 force pounds



Model 246
7,500 force pounds

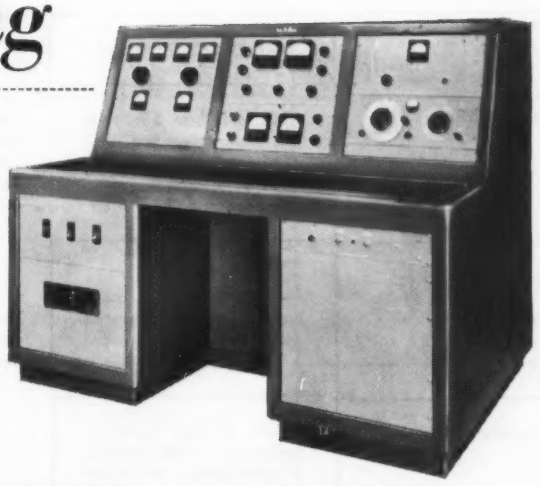
CONTROL CONSOLES

Ling Master Control Consoles provide the operator with a continuous indication of system performance and give finger-tip control of the completely integrated vibration testing program. Your choice of space-saving rack-mount or streamlined desk-type consoles. Extra panel space and wiring ducts are provided for future expansion or for optional equipment that can be engineered into the consoles to meet your specific requirements.

vibration test systems for and sine wave testing

SHAKER FORCE OUTPUT

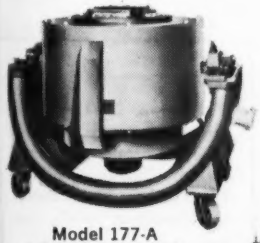
Shaker	Power Supply	Rated Continuous Output In Watts	Amplifier Plate Dissipation In Watts	Sine-Wave lbs.-Force Vector	Random Noise with load equal to Armature Weight lbs. Force RMS	lbs. Force Peak	Armature Protector required
A88	PA-500	500	600	100	70	210	—
227	RP-1/2	1,000	2,000	150	110	330	—
219	CP-3/4	3,000	4,000	500	350	1,050	—
A174	CP-3/4	3,000	4,000	1,200	—	—	—
A174	CP-5/6	5,000	6,000	1,500	800	2,400	AP-5
A174	PP-10/12	10,000	12,000	1,500	1,200	3,600	AP-10
245	PP-10/12	10,000	12,000	2,000	1,200	3,600	AP-10
177	PP-10/12	10,000	12,000	3,150	2,800	8,400	AP-10
177	PP-20/24	20,000	24,000	5,000	4,000	12,000	AP-10
177	PP-30/40	30,000	40,000	5,000	4,500	13,500	AP-30
246	PP-40/60	40,000	60,000	7,500	5,600	16,800	AP-30
182	PP-30/40	30,000	40,000	10,000	11,000	33,000	AP-30
182	PP-75/90	75,000	90,000	15,000	17,000	51,000	AP-40
A182	PP-75/90	75,000	90,000	17,700	17,000	51,000	AP-40
A182	PP-175/240	175,000	240,000	25,000	26,500	79,500	AP-60
249	PP-175/240	175,000	240,000	25,000	26,500	79,500	AP-60



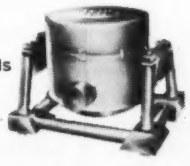
SINE-O-MATIC

The Ling Sine-O-Matic is a completely packaged system, designed and priced to make sine-wave reliability testing practical and profitable for all potential users. It features fully automatic programming and operation, with all components (except the shaker) in a single, compact console.

Several systems are available, with a choice of outputs from 25 to 1500 pounds peak force. No impedance changing or manual power factor correction is required over the entire frequency range. Frequencies range from 5 to 10,000 cps.



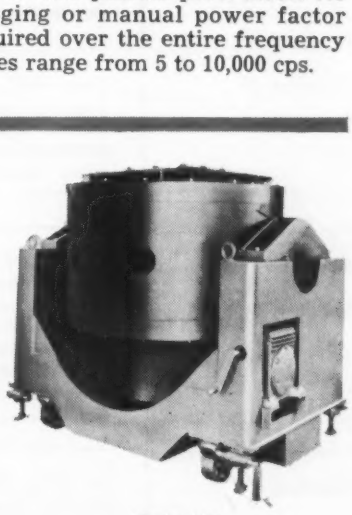
Model 177-A
5,000 force pounds

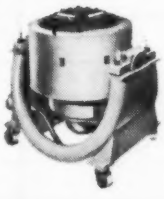


Model 245
2,000 force pounds

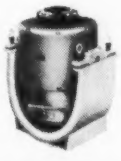
Model 227
150 force pounds

Model A-88
100 force pounds





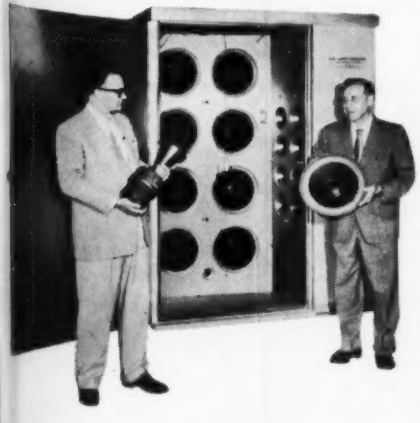
Model A-174
1,500 force pounds



Model 219
500 force pounds

Model 6-C
25 force pounds

Model 182
15,000 force pounds



ACOUSTIC VIBRATION

Acoustic vibration represents a major advance in the field of vibration testing—an advance that has been paced by Ling's development of complete acoustic vibration systems. These integrated systems include acoustic chambers built to the user's specific vibration requirements, and giant loud speakers or whistles driven by Ling Power Generators. A Ling acoustic system extends the frequency range of vibration testing to meet today's newest problems.

LING ELECTRONICS, INC.
Factory Sales Offices:
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120 Cross Street, Winchester, Massachusetts

CIRCLE 38 ON INQUIRY CARD

TABLE I*
CHART OF ENVIRONMENTAL TEST SPECIFICATIONS

ENVIRONMENTAL TEST	SPECIFICATIONS			
	MIL-E-005272B (USAF)	MIL-E-5400B (ASG)	MIL-T-5422C (ASG)	MIL-STD-202
HOT TEST	71C, less than 5% relative humidity, test unit at 71C, duration: 50 hrs. (results compared with room condition operation.	To +260C, depending on class of equipment and duty. Temperatures constant or varying at 1C/sec.	+85C non-operating +71C operating and testing. Durat on: Part of complex cycling.	+85C, 30 minutes cycles, non-operating.
COLD TEST *Procedure I*	—54C, test at —54C, duration: stabilization (results compared with room condition operation.)	To —54C, operating, —62C non-operating, Long exposure to temperature extremes and temperature shock.	—62C non-operating. —54C operating and testing. Duration: Part of complex cycling.	—55C, 30 minutes cycles, non-operating.
Procedure II	—62C, 48 hrs. check deterioration —54C, 24 hrs. or stabilization whichever longer. Test at —54C. Results compared with room condition operation; check for deterioration.			
HUMIDITY *Procedure I*	Temp. +71C, R.H. 95% non-operating, 240 hrs. of cycling, 10 cycles, compared with room condition operation: check for deterioration.	Humidities to 100%, including condensation conditions. During all operating and non-operating conditions.	Temp. +71C, R.H. 95% non-operating. Duration: 240 Hrs. part of complex cycling.	Temp. 40C, R.H. 95% non-operating. Duration: 250 hrs.
Procedure II	Temp. 49C, R.H. 95% non-operating. Duration: 360 hrs. results compared with room condition operation; check for deterioration.			
ALTITUDE *Procedure I*	Pressure, 23.98 inches, (Hg.Abs.) Temp. —55C, test and operate under these conditions. Duration: Per detail specifications. Results compared with room condition operation.	From sea level to 80,000 feet, operating and non-operating, depending on class of equipment. May vary at ½" Hg per second.	Pressure 3.44 inches. (Hg.Abs.) Temp. —55C; operate and test under these conditions. Duration: Part of complex cycling procedure.	Pressure 3.44 inches. (Hg.Abs.) Temp. not specified. Duration: Per detail specifications. Dielectric breakdown per detail specifications while at this reduced pressure.
Procedure II	Pressure 3.44 inches, (Hg.Abs) Temp., —54C, test and operate under these conditions. Duration per detail specifications. Results compared with room condition operation.			
Procedure III	Conditions specified in detail specifications.			
Procedure IV	Conditions specified in detail specifications.			
Procedure V	Pressure 1.32 inches, (Hg.Abs) Temp. —54C, test and operate under these conditions. Duration: Per detail specifications. Results compared with room condition operation.			

*This chart is an up-to-date version of a chart published in Servomechanisms Inc. Engineering Review, Jan. 1957.

TABLE 1 cont.

ENVIRONMENTAL TEST	SPECIFICATIONS			
	MIL-E-005272B (USAF)	MIL-E-5400B (ASG)	MIL-T-5422C (ASG)	MIL-STD-202
SALT SPRAY	Temp. 35C, R.H. greater than 85%, salt solution 20% ± 2%, 99.8% pure salt. Duration longer than 50 hrs., non-operating; Results compared with room condition operation. Salt deposits may be removed prior to operation.	Operate and non-operate in salt-sea atmosphere.	Same as MIL-E-5272B (USAF)	Same as MIL-E-5272B (USAF)
FUNGUS	Temp. 30 ± 2C, R.H. 95% ± 5%. Fungus: 5 types. Duration: 28 days, non-operating check for deterioration.	Operate and non-operate when exposed to fungus encountered in tropical climate.	Same as MIL-E-5272B (USAF)	None.
SAND AND DUST *Procedure I*	Density: 1 to 5 grams per cubic foot. Velocity: 2300 ± 500 Ft/min., R.H. never more than 30%. Duration: 6 hrs. at 25C, 6 hrs. at 71C. Results compared with room condition operation. Check for deterioration.	Operate and non-operate on exposure to sand and dust as encountered in desert areas.	Duration: 6 hrs. at 71C. Non-operating.	Same as MIL-E-5272B (USAF)
Procedure II	Conditions same as Procedure 1. Duration 8 hrs. at 25C and test at 71C deleted.			
IMMERSION	Liquid water or equiv. Temperature: room. Pressure: 1 inch (Hg.Abs.) Examine for leaks. Increased to 2½ inches.	None.	None.	Liquid Saturated salt solution or water. Temperature: +65C. Examine and test.
ACCELERATION *Procedures I & II*	Acceleration: per detail specifications. Duration: 1 min. tests per detail specifications during acceleration.	None	None.	None.
TEMPERATURE AND ALTITUDE	Complex cycling of conditions at combinations of pressures and temperatures.	Temperature altitudes requirements call for temperature to 260C at sea-level depending on class of equipment.	Same as MIL-E-5272B (USAF)	None.
EXPLOSION *Procedure I*	Temperature +52C to 71C. Unit to operate in explosive mixture of butane and air at altitudes up to 40,000 ft. Different fuel mixtures required.	No ignition shall be caused when equipment is operated in an explosive mixture.	*Procedure I* Same as MIL-E-5272B (USAF) *Procedure I*	
Procedure II	Unit to be filled with explosive mixture and placed in chamber with explosive mixture. The mixture in the unit is ignited at equivalent altitudes up to 5,000 ft.		*Procedure II* Same as MIL-E-5272B (USAF) *Procedure II*	

TABLE I Cont. CHART OF ENVIRONMENTAL TEST SPECIFICATIONS

ENVIRONMENTAL TEST	SPECIFICATIONS			
	MIL-E-005272B (USAF)	MIL-E-5400B (ASG)	MIL-T-5422C (ASG)	MIL-STD-202
SHOCK *Procedure I*	Shock test per detail specifications, operating. Equipment, Jan. 5 - 44.		Same as MIL-E-5272B (USAF) *Procedure II*	Same as MIL-E-5272B (USAF) *Procedure I*
Procedure II	1. Equipment, MIL-S-4456, Shock: 15g, 11 ± 1 millisecond. Duration: 18 shocks, 6 in each axis. 2. Shock mount with a dummy load 30g 11 ± 1 millisecond. Duration: 6 shocks.	1. With vibration isolators in place, 18 shocks of 15g on 3 axes, 11 ± 1 millisecond. 2. 12 shocks of 30g along 3 axes, 11 ± 1 millisecond. Bending and distortion permitted.		
Procedure III	Per detail specifications. Machine per MIL-S-901. High impact.			
VIBRATION *Procedure I*	For assembly mounting on aircraft. Resonance search: 5 to 500 cps, 10g max; cycling 10-55 cps., 10g max.	Normally mounted, including vibration isolators, 5-500 cps, ±10g max. Vibration isolators removed, 5-500 cps. ±2g.	Same as MIL-E-5272B (USAF) *Procedure XI*	Duration—2½ or 5 hours: Frequency: 10-55 cps, double amplitude —.06"
Procedure II	For assembly mounting directly to recipricating engines. Resonance search: 5 to 500 cps.; 20g max. Vibrate at resonant frequencies.		Same as MIL-E-5272B (USAF) *Procedure XI*	Duration: 2½ or 5 hrs. Frequency: 10-55 cps. double amplitude —.06"
Procedure III	For assembly mounting on vibration isolated portions of aircraft. Resonance search: 5 to 55 cps.; 1 5g max.; Vibrate at resonant frequencies.			
Procedure IV	For panel mounted instruments, resonance search: None. Cycling: 5-50 cps. at amplitude determined by detail specifications.			
Procedure V	Same as IV except amplitude is .018" to .020" double amplitude. To test for faulty construction in panel mounted instruments.			
Procedure VI	For rotary equipment. The equipment to be vibrated torsionally through 3 degrees at frequencies from 10 to 40 cps.			

MORE VIBRATION TEST PROCEDURES ALL PER SPECIFICATIONS ABOVE

Procedure VII	*Procedure VIII*	*Procedure IX*	*Procedure X*	*Procedure XI*
For alternators and generators, this test is a resonance search from 100 to 500 cps. At max. acceleration of 10g's.	For alternators and generators. This test is a functional weakness test for power equipment mounted directly on aircraft engines.	For testing efficiency of vibration isolators. Tests from 5 to 55 cps. Double amplitude at .036".	For constructional details. Cycling: 6 hrs., 10 to 55 cps. .03" double amplitude. The unit shall also be vibrated from 20 to 200 cps, at 10g max. acceleration.	Cycling with shock mounts 10 to 55 cps. at .06" double amplitude. 4½ hrs. in 3 directions. Cycling without shock mounts for 6 hrs. at 5 to 500 cps. Double amplitude of .01" or 2g's whichever is limiting factor.

TABLE II

BRIEF DESCRIPTION OF ENVIRONMENTAL TESTS

TEST	BRIEF DESCRIPTION	TYPES OF FAILURES
TEMPERATURE	Chambers available to temperatures of 1000°F to 1400°F. Constantly higher temperatures encountered in missile work. Very large chambers for testing of complete systems such as a missile nose cone.	At high temperatures—Metals lose design strength. Insulations weaken. Lubricants fail. Dimensions and fits change. Semi-conductors fail to operate. Capacitor life is reduced. Bearings and lubricants freeze. Moisture condensation can freeze bearings and create noise on potentiometer sliders. Temperature shock can destroy finishes, crack seals; wide temperature ranges are a principal problem in the design of temperature compensated equipment. Temperature failures constitute a principal source of environmental failure.
SHOCK	Shocks are imposed by hard landings, transportation over rough terrain, weapon firing, rapid accelerations, and a variety of other causes. Shock tests are carried out using standard test equipment as described in particular government specifications. Missile applications have increased the need for devices producing a precise and reproducible shock pattern. Shock testing equipment may be based on impact with a swinging hammer under precisely defined conditions, dropping from a prescribed height on to a bed of sand, acceleration in a pneumatic cylinder, dropping on a platform which is stopped by a lead pellet, etc. Crystal type accelerometers having an extremely rapid time response are used to calibrate these machines.	Shock failures usually take the form of deformed or broken parts. Fastener failures are common. Sometimes an entire framework of a sub-system may be deformed or fractured. Brush contacts may open up. Tube filaments may open. The other electrodes of a vacuum tube may short circuit, or become structurally weakened as to generate microphonics. In general, smaller components having little mass are far less sensitive to shock.
VIBRATION	This is one of the more severe environmental problems encountered in current requirements. Early military specifications calling for vibration testing from 5 to 55 cps are being superceded by more stringent requirements covering the range to 2000 cps. For the lower frequency a straight-forward mechanical shake table is employed, energized by an adjustable speed motor through a driving linkage. Cam arrangements can be incorporated for cyclical speed variations over the band. Amplitude control is also required. Higher frequencies are covered by loud-speaker type devices with the shake-table attached to the "voice coil." Power is derived from a variable frequency supply, which may be an alternator driven by an adjustable speed motor, or a power amplifier energized by a variable frequency oscillation.	Vibration tests introduce electrical contact failures in potentiometers, relays, and devices with brush contacts, fatigue failures at flanges, and other stressed portions of cantilevered members, loosening of fasteners, intermittent contact of tube elements, failure of solder joints, wear and misalignment in shafts and bearings, opening up of electrical connections, breaking of lead connections, and the greatest variety of other mishaps. As with shock tests, smaller encapsulated units are most resistant to vibration. Resonances should be avoided where possible. Frames and shells should be sufficiently stiff to avoid resonances in the test band. Webs and dimples will add stiffness without increasing mass and lowering resonant frequency. Shock mounts are widely used, although on occasion they can accentuate a dangerous resonance. Silicone rubber may be poured or tucked into the corners of sub-assemblies to provide a damping support. Shock mounts are of no value in the face of vibration induced by acoustic noise, described elsewhere in this digest.
HUMIDITY	Designed to assure reliable operation after storage in humid areas. Humidity and temperature must be simultaneously regulated. Humidity may be controlled by heaters in distilled water, or by spraying water against rod or strip heaters. Humidity may generally be varied from 5% to 95%.	Corrosion of certain materials on unprotected surfaces. Reduction of insulation resistance due to moisture absorption by certain materials. Dimensional changes in certain materials. Injurious to potentiometer contacts. Humidity can create short circuits. Accumulation of moisture in hydraulic lines can be especially serious. Humidity followed by a sudden drop in temperature can cause ice accumulation with occasional disastrous results.
SALT SPRAY	To simulate marine environment. Test performed by pumping a standard salt solution through a nozzle as a fog in a salt spray chamber. Baffles prevent direct infringement of salt particles on test samples. Washing away excess salt is often permitted before re-testing units having rotating output shafts.	Causes severe corrosion due to electrolytic action. Causes binding of rotating members, malfunctioning of electrical damage and possible chemical attack on certain lubricants. Suitable design techniques and finishes have minimized the difficulty of meeting salt spray requirements.
EXPLOSION	Explosion tests are of two varieties, to see whether equipment operating in an explosive atmosphere will cause an explosion, or whether an externally caused explosion will fragmentize the equipment. Explosion tests are conducted at high ambient temperatures. Lean, intermediate, and rich fuel mixtures are prescribed.	Explosion tests are of extreme importance because of the probable disastrous consequences of failure. Sparks at contacts, commutating and slip rings, or even sparks generated by mechanical impact of certain materials may initiate an explasion. Cutout switches, circuit breakers and relays can be offenders. Arcing due to insulation

(continued next page)

THE FIRST COUNT-DOWN WAS . . .

Inside AN R.F. SHIELDING ENCLOSURE

Proper functioning of critical missile electronic guidance systems demands exhaustive pretesting in the laboratory, on the production line and at the launching site. One very important pre-testing procedure is analyzing the performance of electronic components, sub-systems and systems in an area completely free of RF interference.

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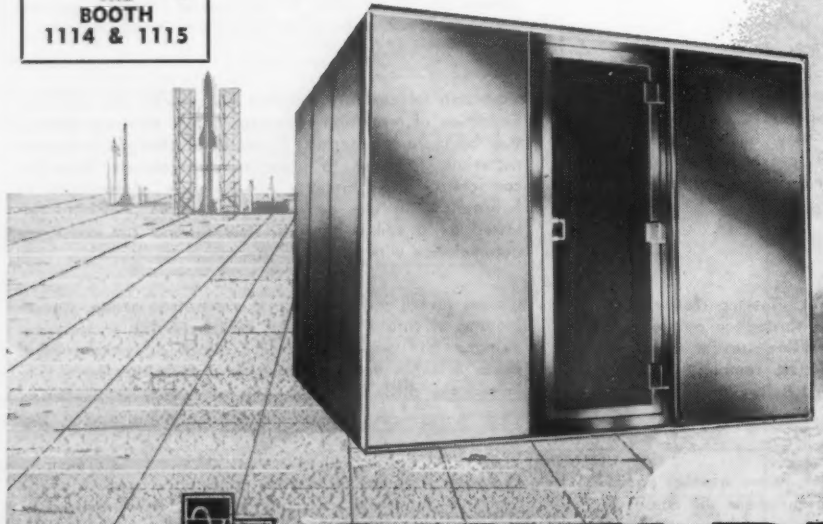

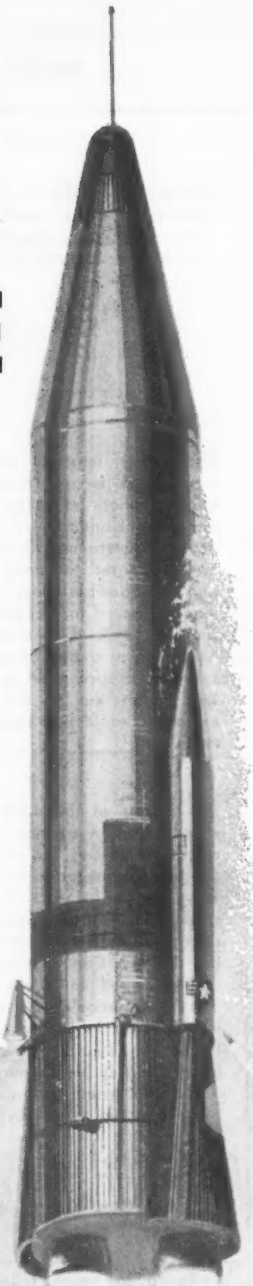

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CIRCLE 39 ON INQUIRY CARD

TABLE II cont. ENVIRONMENTAL TESTS

TEST	BRIEF DESCRIPTION	TYPES OF FAILURES
EXPLOSION *(continued)*		failure may cause an explosion. Construction which permits destructive fragments to be scattered by an explosion can cause damage over a wide area.
SAND AND DUST	Sand and dust conditions are encountered primarily in dry, desert-like areas. Tests are performed in special chambers comprising a blower, ducts, and heaters to generate specified ambient temperatures. Military specifications define the size and composition, and velocities of the particles used in test.	Sand and dust are particularly injurious to ball-bearings of rotating components, and devices having gearing and other moving parts. Unsealed contacts on relays, slip rings, and commutators, and potentiometer contacts, are sensitive to minute dust particles. The best design protection is to provide appropriate seals and dust covers. The contact pressures required to maintain good performance in the presence of shock and vibration are not usually in themselves adequate for dust particles. Hermetic sealing or encapsulation is carried out in critical instances such as relay contacts.
FUNGUS	High temperatures and humidities in tropical areas promote the growth of fungus, which consumes materials damages finishes, causing a great variety of failures. It is remarkable how many engineering materials represent "good eating" for fungus. Fungus growth may be countered by use of only fungus resistant materials, which contain no nutrients, or by a suitable protective coating of nutrient materials. Equipment is generally designed directly to resist fungus, and fungus tests are therefore frequently waived. Fungus tests are carried out by spraying the equipment with a water suspension of fungus spores, and then storing at 30°C and 95% relative humidity for 28 days.	Fungus consumes many of the standard construction materials. Because fungus resistant materials or coatings are readily available and widely used, the problem of fungus resistance is not a severe one. Failure is usually associated with some overlooked design detail which may be readily corrected. Fungus failure in its milder forms can obscure name-plates or read-out points, ruin finishes, etc., while, more seriously, it can completely wreck the proper operation of the equipment.
SUNSHINE	Sunshine tests are accomplished by exposure to lamp of spectral distribution simulating strong sunshine. Radiant energy is applied of 100 to 120 watts per square foot in specified wavelengths. Temperature is held at 113°F.	Sunshine may cause fading of colors, darkening of glass, reduced legibility of markings, and readings of meters and dials. Semi-conductors, particularly the photo-sensitive variety, may be influenced by the action of sunshine.
RAIN	The equipment is subjected to the equivalent of heavy rain, small droplets of water being applied, rather than a fine mist as in the humidity test. The equipment is positioned to simulate installation conditions.	Water penetration and resulting damage are similar to effects of humidity, although less difficult to meet from a design point of view. Water may enter principally through openings provided for ventilation.

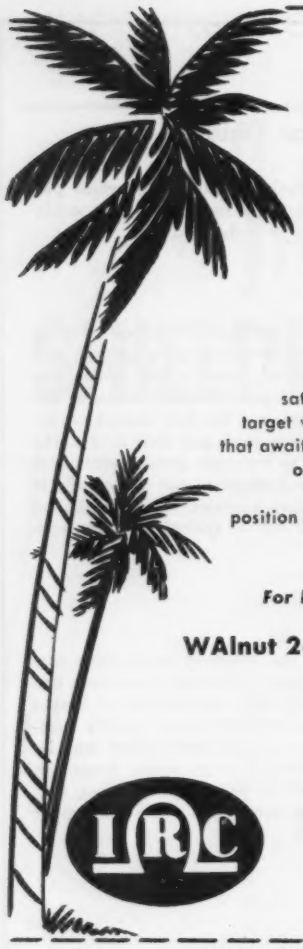
TABLE III

RANDOM AND COMPLEX-WAVE VIBRATION COMPONENTS OF TEST SYSTEM

OBJECT: To produce vibration of the specimen in exact accordance with the system input voltage signal.

INPUT SIGNAL GENERATOR	PREAMPLIFIER	BAND-LIMITING FILTERS	FREQUENCY EQUALIZER	POWER AMPLIFIER	SHAKER
Gaussian noise, Sine-Wave Generator. Tape-Recorder signals, such as missile vibration.	Amplifies input-signals, combines separate components when required.	For control of energy distribution.	For shaker compensation, or to control energy distribution pattern.	Provides shaker power. Taps usually available for proper matching.	Transmits signal generator voltage as an acceleration.

NOTE: Because a gaussian noise signal will contain occasional extremely high peaks, which are uneconomical to amplify, and which can result in shaker over-travel, clipper circuits may be included in the above chain. Commercial equipment incorporates additional protection devices to prevent damage to the shaker, or other major components in the event of a fault.



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COMPONENTS DIGEST

Acoustic Noise Testing

Acoustic noise produced by rocket engines may caus malfunctioning of components that could not be detecte by vibration testing. The principal reason is that acousti noise excitation acts directly on all parts of a component while vibration is applied only at the mounting point. Shoc mounted or vibration isolated components may be ade quately isolated from higher frequency vibrations as a result of the low pass filter characteristics of the mount while such mounts afford absolutely no protection agains acoustic noise. Resonances above the natural frequency o the shock mounts are transmitted directly to the componen by acoustic noise testing.

Failures from acoustic noise testing are similar to th types of failures that occur in normal vibration testing Permanent deformation of parts may be caused by hig peaks that occur in random noise distribution. As wit random vibration testing, simultaneous resonances ma occur within such structures as vacuum tubes. Fastener may loosen, lead connections may break, and fatigue fail ures may occur in panels and structural surfaces becaus of induced resonances. Designing to withstand acousti noise failure is carried out by designing to withstand con ventional vibration failure with the additional condition that excitation is introduced from all directions of th environment and not only through the mounting base This type of design is most realistically carried out by studi of failures, either in the field, or preferably in the tes laboratory.

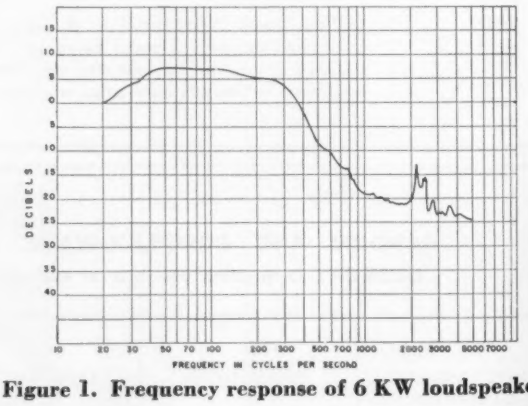
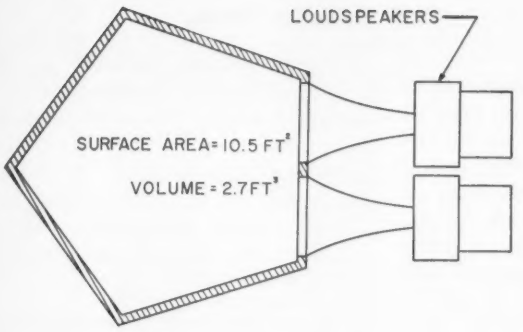


Figure 1. Frequency response of 6 KW loudspeaker

The equipment used for acoustic noise generation i roughly similar to that used for random vibration testing Electronic gear is used to apply controllable excitation t a "loud speaker" type device. Fig. 1 shows the frequency response of a 6 kw loud speaker designed and used by Avc engineers for acoustic noise generation. The output of th speaker is applied to a long tube provided with acousti noise absorbing material at the far end to eliminate reflec tions and standing waves. A random noise signal including component frequencies from 20 to 5000 cps generates a 155 db pressure level (reference 0.0002 microbars) in a 10 inch tube. Levels from 164 to 170 db can be achieve in a 4 inch tube.

A reverberant chamber, producing higher pressures fo a given power input, is used to test larger samples. Fig.



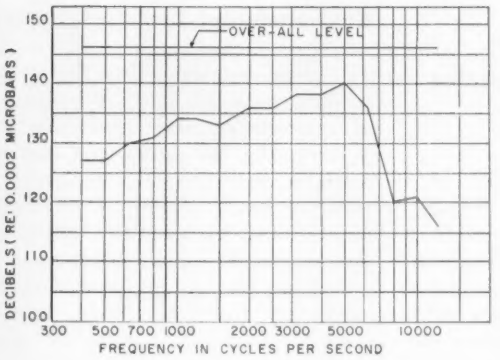
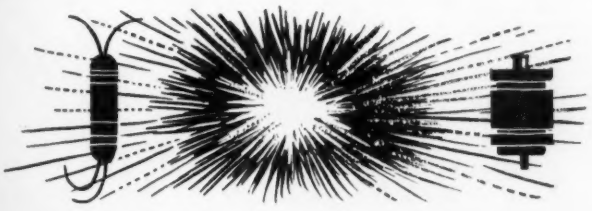


Figure 2. Pentagonal reverberant chamber

shows the frequency response of such a chamber made by Avco. While significant differences exist in the frequency spectra at different points in the chamber, overall sound pressure levels are fairly uniform.

While acoustic noise testing is a recognition of a new environment, study of failures, determination of actual noise environments for more accurate simulation, and establishment of design procedures for components and frames require a period of intensive study.



Radiation Effects

Radiation of atomic particles, particularly neutrons, from nuclear explosions, atomic engines or space particles, constitutes a new and relatively unexplored environment for military components. Many common engineering materials are affected by such radiation. In particular semi-conductors, transistors and diodes, may be badly damaged by exposure. Common high temperature materials such as Teflon and the Silicone greases are adversely affected. Even structural materials such as aluminum experience a change in properties.

The problem is accentuated in reactor work by the superposition of very high temperatures on the radiation environment. The design problem will probably resolve itself ultimately to use of approved materials matched to the intensity and period of exposure. Data on radiation effects is being accumulated constantly. Because of special difficulties in this kind of testing, adequate design procedures should be developed to meet most requirements, with actual tests carried out on a routine basis only as part of the final qualification test, such as is currently done with fungus testing. Of course, a great deal of formal work is required before this condition is achieved.

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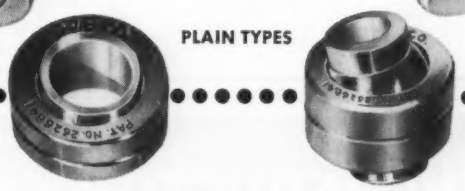

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Source: Unholtz-Dickie Corp.
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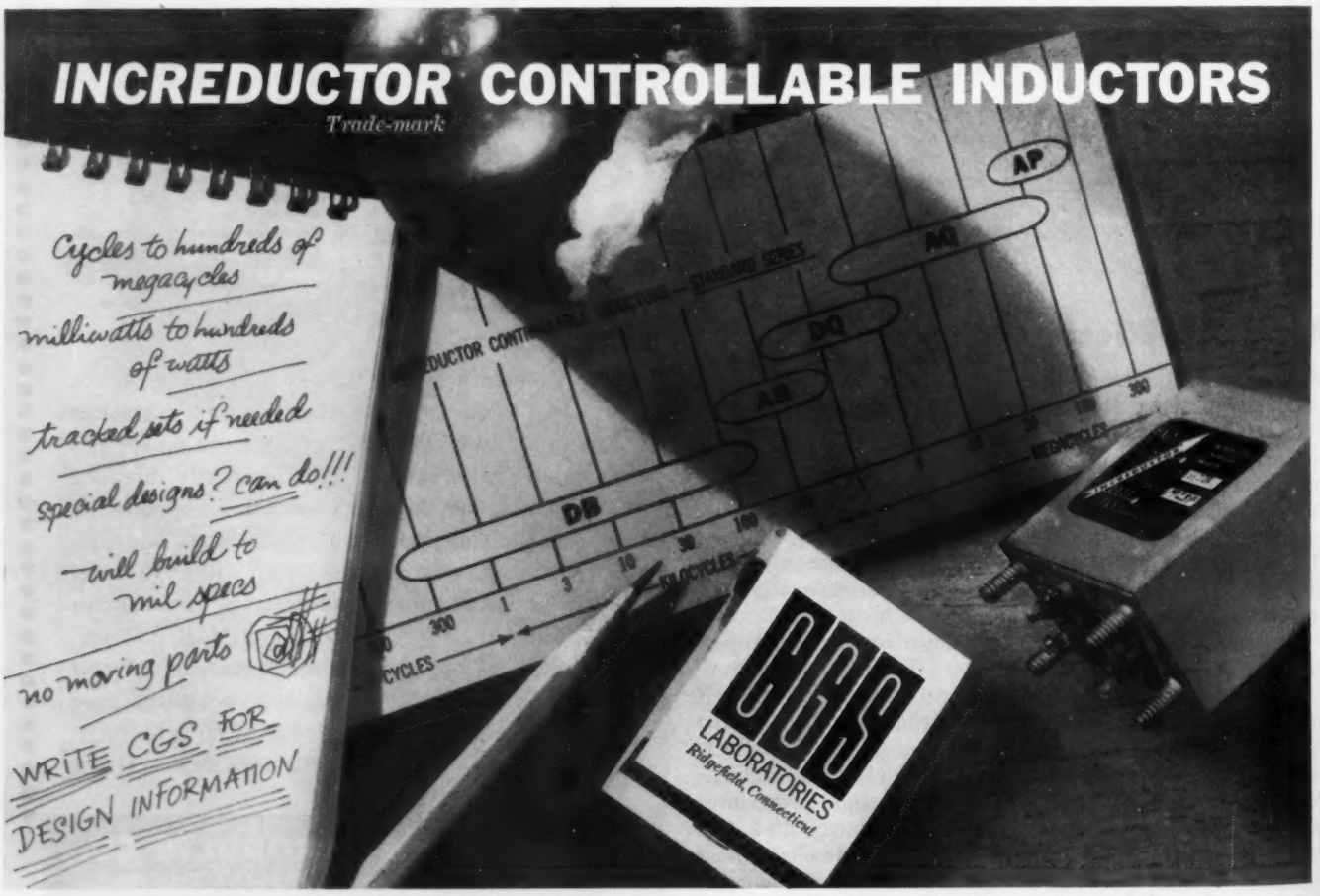

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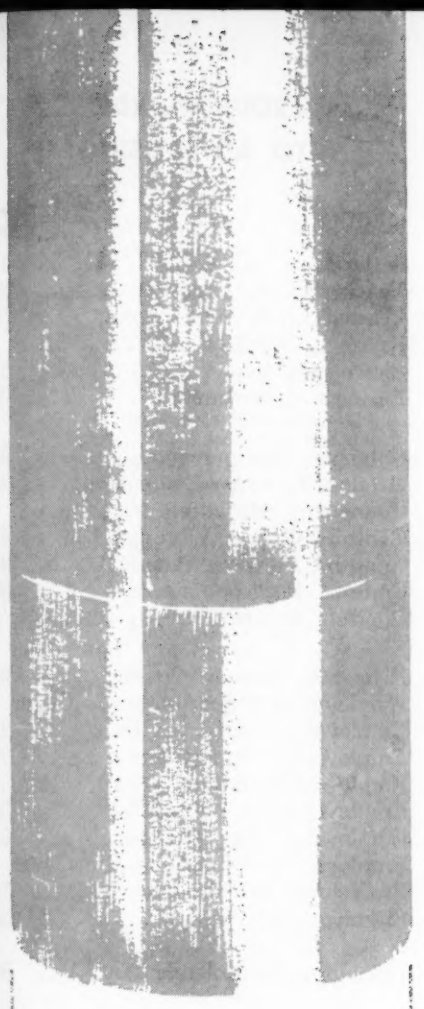

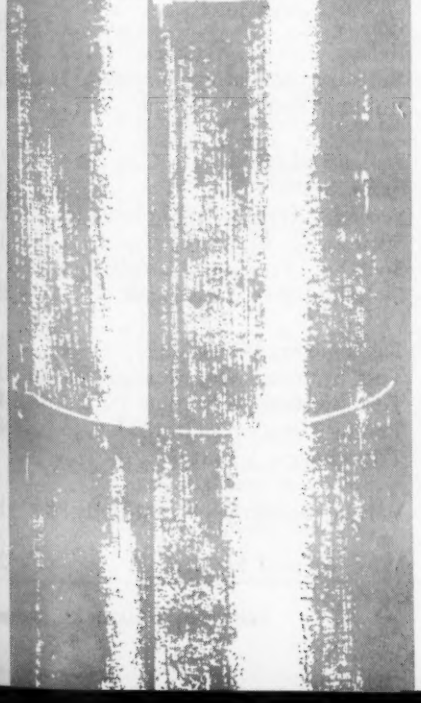

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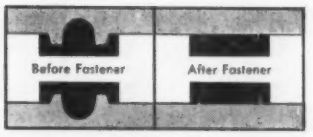

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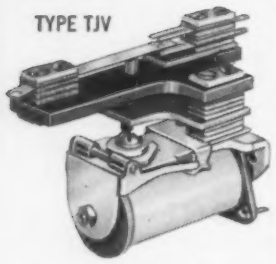

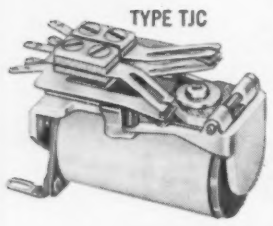

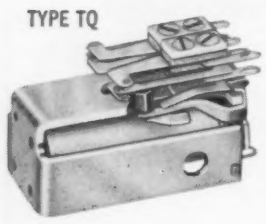

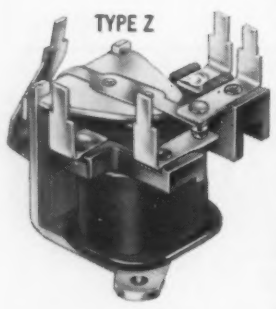

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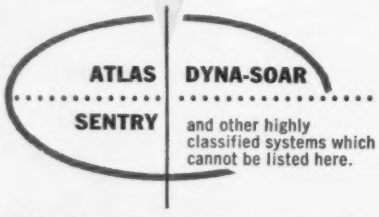

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CIRCLE 47 ON INQUIRY CARD

For Your 3-Ring Binder

NEW DATA SHEETS

For your free copy of the data sheets listed on this page, circle the appropriate number of the item on the Inquiry Card.

Potentiometer Specifications, such as size and dimensions, mechanical requirements and electrical properties of single turn, wire-wound precision potentiometers from ½" diameter to 3" diameter are listed. Units, useful for high reliability in aircraft, missile and ground support equipment are built to applicable requirements of MIL specs as follows: Mil-R-19A, NAS 710, Mil-R-19518, Mil-E-5272A, Mil-R-12934B. Maurey Instrument Corp., Chicago, Ill. Circle 172.

Plain Bearings which are self-aligning and self-lubricating are useful for service requiring low coefficiency of friction, long service life without lubrication and high dynamic load carrying capacity. Tradenamed "Dyflon", these plain bearings are available in a wide variety of both plain types and rod end types in bore sizes from 3/16" to 6" diameter. Rod end types have either externally or internally threaded shanks. Southwest Products Co., Monrovia, Calif. Circle 184.

Ceramic Capacitor cross reference guide lists over 600 ceramic capacitors by type and rating. Equivalent units of other manufacturers, where available, are listed next to the Centralab capacitors, providing an easy method of determining sources for any given capacitor. The guide contains separate sections devoted to general purpose discs and tubulars, temperature compensating discs and tubulars, high voltage discs, dual capacitors, buffer capacitors, low voltage capacitors, stand-off and feed-thru, transmitting, high accuracy and trimmer capacitors. Centralab, Div. of Globe-Union Inc., Milwaukee, Wisc. Circle 243.

Reducer and nonreducer motors of various types and sizes listed in 12-page bulletin. Horsepower ratings of non-reducer motors range from 1/17 to 1/1500. Reducer motors, with speeds ranging from 833 to 0.7 rpm, have torques of 12.8 in. oz. to 219 in. lbs. Bodine Electric Co., Chicago, Ill. Circle 244.

High Temperature Pot has proven itself at 750 F. This metal film pot maintains a resistance stability of ±5% over 300 hours of operation from −55C to +400C. Constructed entirely of metal and ceramic parts, it will withstand nuclear radiation. Fairchild Controls Corp., Components Div., Hicksville, N. Y. Circle 249.

Time Modulated Servovalve for use in electrohydraulic control systems offers advantages in construction of low cost, high performance servomechanisms. Report on this unit discusses theory and merits of this mode of operation and presents data from a typical valve. Eastern Aviation Products, Hamden, Conn. Circle 162.

Potentiometers and Transducers are covered in a complete set of individual data sheets bound into a catalog. Each data sheet gives a complete description, features and application specifications for the particular type of potentiometer or transducer discussed. A handy reference for designers. Bourns Labs, Inc., Riverside, Cal. Circle 228.

Miniature Tape Recorder, the smallest tape recorder brought to our attention, is now available from Leach Corp., Inet Division, Compton, Cal. The unit weighs 24 ounces complete with tape and is 3-5/8 inches in diameter by 2-1/2 inches long. Tape speeds vary from 0.25 to 15 inches per second with recording times from 1 to 60 minutes. The unit is designed for inflight tests, static tests, blast and explosion studies, wind tunnel studies, acceleration tests, actuation tests, oil well logging and atmosphere studies. Leach Corp., Inet Div., Compton, Cal. Circle 225.

Five Shaft Angle Encoders, (13, 16, and 18-digit) described in five, four-page bulletins. Operation and construction features, plus electrical and mechanical specifications are given, along with illustrations and schematic operation diagrams of each unit. Industrial Products Div., The Baldwin Piano Co., Cincinnati, Ohio. Circle 236.

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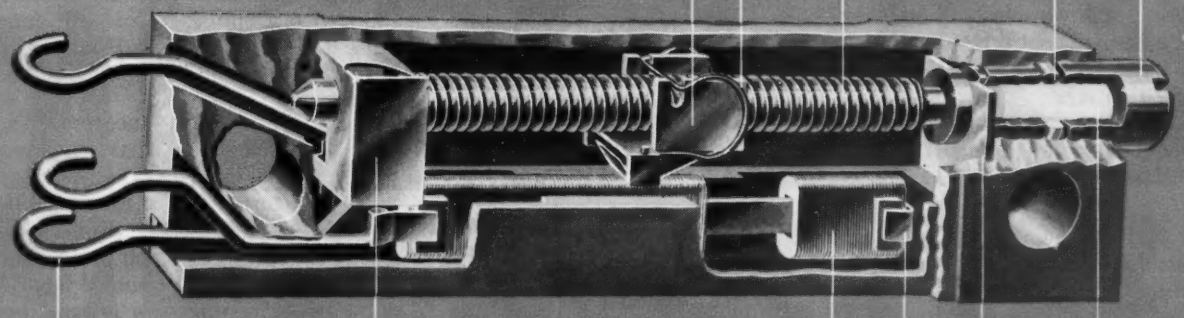

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